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SCALING PARAMETERS FOR THE SIMULATION OF HIGHLY EXPANDED ROCKET EXHAUST PLUMES AND THE RESULTANT IMPINGEMENT FORCES ON AN IMMERSED BODY

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FOREWORD

This document presents results of work performed by Lockheed Missiles and Space Company, Huntsville Research and Engineering Center under Contract NAS8-24437, Scaling Parameters/Low Density Plume Impingement Force Data, to the Aero-Astrodynamics Laboratory of NASA/Marshall Space Flight Center The Technical monitor was Mr V K Henson of the Aero-Astrodynamics Laboratory.

SUMMARY

Literature dealing with the proper scaling of rocket exhaust plumes with nonreacting gas mixtures is reviewed From this background, a technique was developed to select gases which will properly simulate a region of a prototype plume, and the technique is outlined A gas simulant selection computer program is then presented and discussed The computer program performs the gas simulant selection based upon the parameter desired to approximate, i e , impingement forces, Mach number, or Reynolds number Results of this program for two typical engines are discussed

A specific parameter of a region of a prototype plume can, in general, be simulated In particular, the momentum flux of a plume appears to be rather easily duplicated for a definite region of a plume Typical selections resulted in about a three percent error in momentum flux This result lends credence to the goal of simulating experimentally the impingement forces of high altitude plumes on orbital bodies

In addition, the Mach number may possibly be simulated by adjusting gas composition and chamber temperature (These results are based on the possiblity of simulating the condensation phenomena) This simulation does appear to be feasible if the chamber properties can be varied enough to match the point of vapor saturation in the flow field

CONTENTS

NOMENCLATURE

Symbol	
a	speed of sound
A	area
C_v	specific heat at constant volume
C_p	specific heat at constant pressure
D	diameter dimension
E	constant defined by equation of text
f_i	scale factor for the i^{th} parameter
F	force
g	number of molecules per drop
G	generalized function
h	specific enthalpy
H	enthalpy
J	drop formation rate
k	Boltzmann's constant
Kn	Knudsen number
ℓ	representative length
m	mass of molecular of vapor
m	mass flux of gas
M	Mach number
n	weight fraction
N	constant defined by equations of text

N_g	fractional condensation rate
P	pressure
Pr	Prandtl number
r	radius
s	radial distance from exit plane of nozzle
SF	geometric scale factor
T	temperature
v	velocity
V	volume of drop
X	axial direction

Greek

α	Knudsen number correction factor
β	momentum correction factor
γ	specific heat ratio
δ	boundary layer thickness
ζ	surface tension
θ	flow angle
λ	molecular mean free path
μ	viscosity
ν	Prandtl-Meyer expansion angle
ρ	density of gas
σ	collision cross section of molecule
ϕ	nozzle lip angle
ψ	molecular weight of gas

Subscripts

a	ambient conditions
cont	continuum flow conditions
d	drop
e	exit plane
FM	free molecular flow conditions
liq	liquid
m	model
o	stagnation conditions
p	prototype
S_∞	stagnation condition for drop of infinite radius
t	throat conditions

Superscript

*	denotes drop of critical size

INTRODUCTION

Orbiting vehicles of the Apollo Applications Program and other space programs are generally maneuvered by reaction control rocket engines In many cases, interaction and impingement of the exhaust plumes on the parent vehicles create control thrust degradations in conjunction with undesirable reaction forces and moments If these plume impingement effects are not defined, inadequate control systems may result Since orbiting vehicle configurations are generally complex (including extensive external hardware such as solar power cells, communication antennas, etc) theoretical procedures for predicting vehicle plume impingement forces are quite complicated By analyzing properly simulated experimental investigations, impingement forces on complex structures can be adequately defined Because full-size tests are costly and complex, scale model testing should be used To have "proper simulation," the tests should provide good scaled simulation of both the vehicle and the plume, otherwise techniques for applying the test results to a full-scale condition must be developed There are, however, two primary problems involved in this simulation one involves scaling a model in the flow field, (the same problem is encountered in conventional wind tunnel testing of aerodynamic configurations and is scaled on the basis of Reynolds number and Knudsen number), the second problem involves simulating the gas dynamics of the flow properties of the rocket exhaust plume Both problems must be satisfactorily resolved in order to obtain correctly scaled impingement forces from scale model testing

The exhaust plumes of a rocket that operates in a near vacuum are characterized by three flow regimes, (1) continuum center portion, (2) a transitional regime surrounding the continuum region, and (3) a highly expanded free molecular regime which may include flow expanding to a direction more than 90 degrees away from the nozzle centerline The

experimental evaluation of the forces on bodies from such plumes requires that the local plume parameters and model parameters be scaled exactly, or that techniques be provided to relate and correct the test results to full-scale conditions The basic problem is complicated by the fact that in many instances (due to test facility limitations) the plume itself will be modeled with a gas which is different than that of the full scale system Gas dynamic relationships between the model and the full-scale system must therefore be established in terms of

- Plume gas dynamic properties
- Reynolds number of the model in the plume
- Knudsen number of the model in the plume
- Scale model motor chamber conditions and nozzle geometry
- Condensation considerations

With these facts in mind a survey on plume scaling was made of state-of-the-art literature Using results of the survey as a base, a computer program was written which performs a rapid search of possible simulant gas mixtures and selects the mixture that best simulates the prototype plume based on Mach number and momentum considerations The impingement forces predicted by the model simulation are then adjusted by a momentum correction factor to account for discrepancies in the gas dynamic simulation

In the following technical discussion, the more important sources of information are discussed, techniques used in the computer program to test and select a gas mixture are outlined and two sample cases that have been run to provide experience with the method are presented Results for these two cases show that a simulant gas mixture can be selected which will approximate in a scaled experiment the impingement forces on a body immersed in a prototype nozzle plume

Section 2
TECHNICAL DISCUSSION

An integral part of the plume scaling study was a literature survey carried out to obtain a working knowledge of accomplishments in the past several years in the field of scaling techniques Thus, before the approach taken in the current study is described, the work carried out by others is outlined Problems or limitations of the existing methods are examined, which have pointed the way to development of the procedures used in the current effort The work applicable to this study is centered in two areas (1) general scaling of plumes, and (2) analytical models of the plume These subjects are discussed in the following subsections

2 1 LITERATURE REVIEW

Templemeyer (Ref. 1) performed a most pertinent study of the simulation of hot jet exhaust with mixtures of cold gases Since the exact parameters that need to be satisfied in order to simulate one gas with another are not readily obvious, Ref 1 examined a gaseous flowfield and found that by equating specific heat ratio, specific internal energy, pressure ratio and mass flow per unit area, the simulation between a prototype and model was achieved at the exit plane of a nozzle By assuming a perfect gas with constant specific heats, the equations can be reduced to a set of three linear algebraic equations with weight fractions as the unknowns Reference 1 then solved the following set of equations

$$C_{v_p} (T_{op}/T_{om}) = n_1 C_{v1} + n_2 C_{v_2} + n_3 C_{v_3} \quad (1a)$$

$$R_p (T_{op}/T_{om}) = n_1 R_1 + n_2 R_2 + n_3 R_3 \quad (1b)$$

$$1 = n_1 + n_2 + n_3 \quad (1c)$$

where the simulant mixture is made up of three gases By selecting a combination of gases Eqs (1) can be solved to provide the weight fractions, N_1 If the weight fractions are all real numbers, the gas mixture is a possible simulant

With the solution of the above equations, the inviscid flow of a nozzle can be simulated for certain cases The boundary layer thickness ratio (δ/D_e) can be duplicated by duplicating the Reynolds number, or

$$\rho M \sqrt{\frac{\gamma P}{\rho}} \frac{\ell}{\mu}\bigg|_p = \rho M \sqrt{\frac{\gamma P}{\rho}} \frac{\ell}{\mu}\bigg|_m \qquad (2)$$

Since

$$M_p = M_m, \quad \gamma_p = \gamma_m, \quad P_p = P_m$$

is assumed, then

$$\ell_m = \ell_p \left(\frac{\mu_m}{\mu_p}\right)$$

Now since the viscosity of a hot exhaust gas is generally large compared to a cold gas mixture, it is difficult to achieve Reynolds number duplication if the nozzle length is to scale As a result, Ref. 1 resorted to computing a scale factor by which the nozzle length is varied in order to achieve viscous similitude For example in Ref 1 a turbulent boundary layer was assumed and then the boundary layer thickness was expressed as

$$\delta = \ell / R_N^{0.2}$$

and

$$\delta_p (SF) = \delta_m$$

Then

$$\left(\frac{\ell}{\frac{\rho u \ell}{\mu}}\right)^2 \bigg|_p (SF) = \left(\frac{\ell}{\frac{\rho u \ell}{\mu}}\right)^2 \bigg|_m$$

Reducing

$$\ell_m = \left[(SF) \left(\frac{\mu_p}{\mu_m} \right)^{0.2} \ell_p^{0.8} \right]^{1.25}$$

Thus the viscous and inviscid one-dimensional flow properties will be duplicated at the exit plane Several combinations of hydrocarbons were then found that fulfilled the necessary requirements for simulation of the exit plane properties of a turbojet engine

Marsh (Ref 2) developed a technique for searching for combinations of gases that duplicate the exit plane conditions of a rocket nozzle to provide plume flowfield simulation Real gas effects were included in the analysis by a variable ratio of specific heats Basically the following three similarity laws involving P, M, and μ were satisfied

Pressure Ratio $$(P_a/P_e)_m = (P_a/P_e)_p \tag{5a}$$

Nozzle Lip Turning Angle

$$\left. \frac{\gamma_e M_e^2}{\sqrt{M_e^2 - 1}} \right|_m = \left. \frac{\gamma_e M_e^2}{\sqrt{M_e^2 - 1}} \right|_p \tag{5b}$$

Viscosity

$$\frac{D_p}{D_m} \sqrt{\frac{\ell_m}{\ell_p} \left(\frac{\mu_m}{\mu_p} \right) \left(\frac{\rho_m}{\rho_p} \right) \left(\frac{u_m}{u_p} \right)} = 1 \tag{5c}$$

These requirements reduce to the necessity of duplicating γ_e, M_e, and $(\rho U/\mu)_e$ Reference 2 computed these parameters as a function of pressure ratio, chamber temperature and gas mixture. By plotting the data it was possible to determine graphically a binary or ternary mixture of gases which approximate the prototype conditions The gas mixture generally contained one gas with a low specific heat ratio and one with a high specific heat ratio.

Gopin (Ref 3) was also interested in duplicating flowfield conditions near the exit plane of a rocket nozzle and he included the additional requirement that the impingement forces due to the exhaust gases shall be similar With this in mind, Ref 3 then specified that the momentum flux per unit area be similar

That is, momentum flux = $mu = \rho u^2 A$ (6a)

Since $\rho = P/RT$

$$u^2 = a^2 M^2 = \gamma RTM^2$$

Then, momentum flux = $\gamma M^2 PA$ (6b)

Equating prototype and model conditions

$$\gamma M^2 P \Big|_p = \gamma M^2 P \Big|_m \quad (6c)$$

Reference 3 points out that by choosing high density gases, which is almost synonymous with gases having multiple species, a high mass flow rate can be attained Assuming isentropic perfect gas relationships, Ref 3 shows that

$$m/A = \rho u = P/RT$$

$$m/A = \frac{P_o}{\left(1 + \frac{\gamma-1}{2}\right)^{\gamma/\gamma-1}} \sqrt{\frac{\gamma}{RT_o\left(\frac{2}{\gamma+1}\right)}}$$

$$= \sqrt{\left(\frac{\gamma+1}{2}\right)^{-\left(\frac{\gamma+1}{\gamma-1}\right)}} P_o \sqrt{\frac{\gamma}{RT_o}} \quad (7)$$

If P_o, T_o, and γ are assumed to be constant, then mass flow is a direct function of molecular weight Choosing polyatomic gases (multiple atomic species) provides a high mass flow per unit area with a low flow rate of molecules Thus, it becomes much easier to maintain a vacuum

chamber at a high simulated altitude, (i e , low pressure) for a longer period of time Finally, to avoid condensation the simulant gas mixture was heated

With these stipulations in mind, Ref 3 selected several binary gas mixtures from a group of gases that were presumed to have desirable simulation traits An experimental program was undertaken using a mixture of argon and sulfur hexaflouride to simulate the exhaust gases of the J-2 engine Force measurements were made for impingement of the exhaust on an S-II afterbody The major results of interest here are

- Generally there was little change in forces due to a change in specific heat ratio from $1.18 \leq \gamma \leq 1\ 28$, but there was significant variation for $1\ 28 \leq \gamma \leq 1\ 40$
- Although changes in γ result in modifications of the momentum distribution in the exhaust flow field, very small variations have little effect on impingement forces Hence, minor errors in the gas mixture used to simulate γ are negligible

Note that in Ref 3, $M_{e_p} = M_{e_m}$, and thus for similarity, $\gamma_{e_p} = \gamma_{e_m}$ The authors admit that simulating the exit plane momentum by simulating the specific heat ratio is only an assumption, an assumption that has been justified by previous experimental work. (This point is discussed further in Section 2 2 1)

References 4, 5 and 6 are also interested in simulating the impingement of a highly expanded plume on a nearby surface In particular it was desired to simulate the impingement of exhaust gases from the APS ullage motor and the O_2H_2 burner motor on the J-2 engine of the S-II stage The added requirement that non-continuum effects be duplicated makes Refs, 5 and 6 different from the works previously mentioned.

In designating the experimental conditions, nitrogen gas was selected as the simulant gas since it came closer than any other single gas to

matching the prototype engine gas characteristics Also of importance was the fact that nitrogen is readily pumped by helium cryopanels (as are most gases except hydrogen) To achieve proper nozzle exit plane conditions area ratios were selected that would produce the proper Mach number at the exit plane Simulation of Knudsen number throughout the flow field was obtained by duplicating the nozzle exit plane Knudsen number

If flowfield similarity is assumed, as noted above, scaling parameters between model and prototype conditions can be computed

First

$$K_n = \lambda / D \tag{8}$$

Where

$$\lambda \sim m / \sigma^2 \rho \tag{9}$$

Solving for ρ and writing a ratio

$$\rho_p / \rho_m = (SF) \frac{\sigma_m^2}{\sigma_p^2} \frac{\Psi_p}{\Psi_m} \frac{K_{nm}}{K_{n_p}} \tag{10}$$

Thus the density ratio provides scaling of non-continuum gas dynamics between prototype and model To obtain a pressure scale factor between model and prototype conditions it is assumed that pressure can be written

$$P = P_{cont} + \alpha (P_{FM} - P_{cont}) \tag{11}$$

Where α is assumed to be of the form

$$\alpha = e^{-\frac{1}{K_n}} \tag{12}$$

and K_n is based on R_b the local body radius Now if Mach number and momentum flux (Eq 6b) are similar, then scaling relations can be developed to match Knudsen number Or

$$\frac{(P_s - P_{cont})_m}{(P_s - P_{cont})_p} = \frac{e^{-1/K_n}}{e^{-1/K_n}}$$

And

$$P_{s_p} = (P_s - P_{cont}) \left(\frac{a_m}{a_p}\right) + P_{cont\ p} \qquad (13)$$

These scaling parameters (Eqs 10 and 13) produced remarkable agreement between prototype and model conditions of Refs. 5 and 6

In Ref 7, a rocket plume was simulated by the actual combustion of gaseous fuels to simulate the exhaust of a liquid propellant rocket engine A shock tube technique which permitted short run times was used to maintain proper background pressure This technique provided for the duplication of stagnation enthalpy and a good approximation to the desired molecular species concentration The Mach number in the nozzle can be reproduced by simple geometric similarity since the boundary layer was made to scale by maintaining the full scale Reynolds number Full scale Reynolds number was attained by increasing the chamber density This technique has several advantages, the most obvious in that the prototype species concentration can be obtained in the model plume Also by the simple expedient of raising the chamber pressure, the proper Reynolds number can be attained A drawback pointed out in Ref 7 is that the steady state flow conditions over a complex body with concave shapes cannot be obtained in the testing time available.

To obtain the proper mixture of gaseous reactants to duplicate the combustion products of liquid propellants, two basic rules given in Ref 8 are used

1 The atomic composition (i e , atomic species and atom ratios) of the liquid and gaseous propellants must be the same

2 The initial energies of the two propellant combinations must be equivalent (i e , the $\sum_{j=1}^{r} n_j (H_{T_i})_j$ quantities must be the same)

Condition 1 is easily satisfied, however, condition 2 involves a trial and error approach to arrive at a proper mixture of gaseous components

Many techniques (Refs 1 through 7 were some of the most pertinent) have been employed to simulate the flow field of a rocket engine Some techniques appear more applicable to the problem of this present effort for which the basic objectives of the present effort are related here First, a mixture of non-reacting gases is used to simulate plume impingement forces for the hot products of combustion of a liquid propellant engine Second, conditions in the far flow field of a plume are to be duplicated rather than conditions near the exit plane of a nozzle This stipulation leads to the second section of this literature review

2 1 1 Models of plumes

To simulate the conditions in a highly expanded plume, flowfield parameters in the far field region must be predicted After a method is developed that permits the flow field to be predicted, various combinations of gases can be used to simulate the desired flowfield parameters of the prototype plume Many documents first published in this area were basically interested in simulating jet boundary conditions near the nozzle Representative reports are briefly reviewed in the following paragraphs for this problem More extensive discussions which should prove useful in the present study, are then given to models of plumes

Assuming that there is a finite back pressure, the expression for the Prandtl-Meyer expansion angle can be written

$$\frac{\Delta P}{P} = \frac{\gamma M^2}{\sqrt{M^2 - 1}} \left(\Delta \nu\right) + \text{higher order terms} \qquad (14)$$

Thus Goethert (Ref 9) proposed to match the parameters $\gamma M^2/\sqrt{M^2 - 1}$ and θ_j in order to duplicate the jet boundary of a highly underexpanded jet Pindzola (Ref 10) carried out a study in which better boundary similarity was obtained by matching θ_j and $\gamma M^2/\sqrt{M^2 - 1}$, where the Mach number is now based on the boundary conditions rather than on the nozzle exit conditions. Finally, in a later study Herron (Ref 11) concluded that even better simulation was obtained by matching the parameters θ_j and M/γ All these results were obtained through experimental research

As shown, these studies are not quite applicable to the problem currently under study, however, they were mentioned to underline previous work in jet plume simulation Although the present effort is directed toward simulating plumes at high altitudes, it may prove useful at some later date to add the capability of simulating the shape of a plume near the nozzle With this in mind, attention is now turned to the problem of similarity parameters for highly expanded plumes far downstream Little work has been done previously in the area which is the objective of the present study

To accomplish this objective the first task is to predict flowfield conditions for a highly underexpanded rocket nozzle of given conditions The method-of-characteristics solution has been shown to be a highly accurate technique to describe analytically the flow field of a rocket plume The method is accurate even for highly expanded plumes (Ref. 11) Method-of-characteristics solutions are relatively fast on a computer, however, for far field flow prediction, a source flow model has been found to be faster and to agree closely with method-of-characteristic solutions (Fig 1) A description of this method as given by Ref. 12 is next outlined

Consider the exhaust jet of an ideal inviscid gas issuing isentropically into a vacuum. The flow is steady and the ratio of specific heats is constant At large distances from the nozzle the streamlines seem to emanate from a source near the nozzle exit It is then assumed that the pressure rapidly approaches zero and thus the velocity can be assumed to be constant The

density then takes the form $\rho \sim 1/h^2$, where h is the radial distance from the nozzle exit (Fig 2 from Ref 13) It is assumed that the density on a spherical cap of distance h is of the form,

$$\rho / \rho_e = \frac{E}{2} \left(\frac{h}{r_e} \right)^{-2} \cos^N \theta \qquad (15)$$

Then solving the equation of continuity and momentum for the unknown constants N and E, (Ref 12) obtains the following expression for Mach number

$$M = \left[\frac{2}{\gamma-1} \left\{ \left[\frac{E}{2} \left(\frac{A_t}{A_e} \right) \left(\frac{h}{r_e} \right)^{-2} \left(\cos\theta \right)^{E-1} \left(\frac{\gamma+1}{2} \right)^{\frac{1}{\gamma-1}} \left(\frac{\gamma-1}{\gamma+1} \right)^{\frac{1}{2}} \right]^{1-\gamma} - 1 \right\} \right]^{\frac{1}{2}} \qquad (16)$$

Thus Mach number is dependent only upon the location in the flow field for a given gas and nozzle geometry The most obvious shortcoming of this analysis is the restriction to systems with a constant ratio of specific heats

References 14 and 15 also discuss the similarity of highly expanded rocket exhausts These references, however, are devoted to the description of flow fields inside a barrel-shaped shock emanating from the Prandtl-Meyer expansion fan Thus, these studies are not quite applicable to the current problem which considers expansion into a vacuum

This brief discussion concludes the literature review of simulation parameters and plume models The techniques outlined in the next section draw liberally from the sources which were discussed In many cases, slightly different methods are employed because of complicating factors in the problem at hand

2 2 METHOD OF APPROACH

Obviously a simulation of a full-scale rocket plume could be attained by duplicating Reynolds number, chemical species, Mach number, stagnation

enthalpy, and environmental pressure Noncontinuum effects would automatically be satisfied, since Knudsen number is defined by the Mach number and Reynolds number Since in the present analysis the chemical species cannot be simulated, the Mach number distribution will not necessarily be identical throughout the prototype and model plumes In addition, simulating stagnation enthalpy as obtained by Ref 6 is difficult, since the extremely high total temperature attained in the prototype case is out of the range of the experimental test equipment that is available

As an introduction to the problem of simulation, the rules of flowfield similarity are reviewed here With this requirement in mind, the model established to analytically test a gas for simulation ability is discussed The computer program which was written to select a simulant gas mixture is next described Finally, analytical results comparing impingement forces predicted from model conditions are compared with those predicted for prototype conditions

2 2 1 Similarity Parameters

For two flow fields to be comparable in the region of interest, the terms in the equations of flow must be similar To simplify the calculations, the analysis is carried out one-dimensionally Writing the one-dimensional flow equations,

Momentum

$$u \frac{du}{dx} = \frac{1}{\gamma M^2} \frac{dP}{dx} + \frac{1}{R} \frac{d^2u}{dx^2} \qquad (17)$$

Energy

$$u \frac{dT}{dx} = \frac{1}{P_r R_n} \frac{d^2T}{dx^2} + (\gamma-1) M^2 u \frac{dP}{dx} + \frac{4}{3} \frac{(\gamma-1)M^2}{R_n} \frac{d^2u}{dx^2} \qquad (18)$$

Equation of State

$$P = \rho RT \tag{19}$$

Continuity

$$\frac{d(\rho u)}{dx} = 0 \tag{20}$$

The equations of state and continuity add no new information to the dimensional analysis and are included only for the sake of completeness Thus, from momentum, equivalent terms from the model and prototype situations can be equated On

$$\gamma_p M_p^2 = \gamma_m M_m^2 = f_1 \gamma_p f_m^2 M_p^2$$

where f_1 is a scale factor for the i^{th} variable

Then

$$f_m = \frac{1}{\sqrt{f_1}} \tag{21}$$

Similarly, from the energy equation

$$(\gamma_p - 1) M_p^2 = (\gamma_m - 1) M_m^2 = (f_1 \gamma_p - 1) f_m^2 M_p^2$$

Or

$$(\gamma_p - 1) = (f_1 \gamma_p - 1) f_m^2$$

Substituting from the momentum equation into the energy equation yields

$$f_1 = 1 \tag{22}$$

Thus for complete flowfield similarity, all of the following parameters must be equated

$$\gamma_p = \gamma_m \tag{23a}$$

$$M_p = M_m \tag{23b}$$

$$Rn_p = Rn_m \tag{23c}$$

$$Pr_p = Pr_m \tag{23d}$$

Complete similarity may never be achieved, however, since the primary interest in this study is the force produced on a body immersed in a rocket exhaust plume Conditions leading to force similarity are examined The force exerted on a body can be written in the general form

$$F = G \quad (\rho, u, \ell, \mu, a) \tag{24}$$

Using dimensional analysis, the expression can be written in a familiar form

$$\frac{F}{\rho u^2 \ell^2} = G\left(\frac{\rho u \ell}{\mu}, \frac{u}{a}\right)$$

If viscous effects are ignored, then

$$\frac{F}{\rho u^2 \ell^2} = G(M) \tag{25}$$

But this expression can be written in more familiar terms as the pressure coefficient

$$\frac{F}{\rho u^2 \ell^2} = \frac{\Delta P}{\rho u^2} = G(M)$$

Or

$$C_p = \frac{\Delta P}{2\rho u^2} = G(M) \tag{26}$$

Thus, for identical gases, if the Mach number is equal, the pressure coefficient C_p is identical However, the pressure exerted on a body is also a function of gas composition or γ In other words, pressure is a function of momentum flux ρu^2 and Mach number, where

$$T = \text{momentum flux} = \rho u^2 = \gamma P M^2 \tag{27}$$

Now, as shown in Ref 3, the impingement pressure can be duplicated by approximating the momentum flux This assumption is also borne out by the work of Ref 4, in which computation of the impingement pressure by Newtonian calculations is analogous to computing the momentum flux Thus, when a duplication of impingement pressure was desired, a simulant gas mixture has been selected on the mixture's ability to duplicate momentum flux at a point in the plume In addition, options have been included in the computer program that will compare Mach number or Reynolds number and select a simulant gas mixture that best duplicates the parameters

2 2 2 Gas Selection

As stated in the introduction, two objectives of the study are (1) select a binary or tenary mixture of gases to simulate in a scaled model the forces produced on a body immersed in a plume, and (2) include real gas effects in the analysis and attempt to duplicate such esoteric flowfield phenomena as condensation

An ideal technique to strive for is to develop a closed form solution for the mixture ratios of a possible simulant gas (Ref 1) However, since real gas effects are to be included in the analysis, this avenue of approach is closed If as in Refs 2, 3 and 5 duplication of exit plane conditions will

suffice to duplicate the entire flow field of interest, once again the analysis is simplified But, as shown in Ref 5 the immersed body is relatively close to the exit plane of the nozzle and the specific heat ratio in that region is relatively constant at 1 4 In the present study, the specific heat ratio varies from about 1 3 at the exit plane to 1 4 in the expanded region

To duplicate this specific heat ratio, the technique suggested in Ref 2 was adopted Using gases suggested by Refs 1, 3 and 16, the gases were separated by inspection into three basic groups, those which

1 Exhibited high γ
2 Exhibited low γ, and
3 Those that would condense relatively soon in an expanding gas

Some of the more obvious reasons for eliminating a gas from the above groups are

1 Toxic or easily formed toxic compounds
2 Cost and availability
3 Condensability

However, an extremely important criterion is the ability of the gas to be pumped by helium or nitrogen cryopanels in vacuum chambers For this reason hydrogen will generally be deemed non-acceptable unless its mixture ratio in the simulant gas is very low The actual limits are determined by the capability of the facility available for testing One additional comment should be included concerning the thermodynamic properties of the gases used as possible simulants Thermodynamic properties in highly expanded plumes were desirable where temperatures much below 100°K occur Thus thermodynamic properties good down to 10°K were generated and stored on magnetic tape using the methods of Ref 17 A list of the gases currently on the data tape which can be used as possible simulant gas components is given in Table 1

Table 1

GASES CURRENTLY AVAILABLE FOR ANALYSIS
AS POSSIBLE SIMULANTS

Chemical Formula	Name	Molecular Weight	Ratio of Specific Heats at 1 atm Pressure
A	Argon	39 948	1.667 at 86°F
$CClF_3$	Carbon Chlortrifluoride	104 465	1 2 at 77°F
CF_4	Carbon Tetrafluoride	88 01	1 217 at 100°F
CHF_3	Trifluormethane	70 018	1 22 at 30°F
CO_2	Carbon Dioxide	44 01	1 3 at 86°F
H_2	Hydrogen	2.016	1 4 at 86°F
N_2	Nitrogen	28 02	1 405 at 26°F
N_2O	Nitrous Oxide	44 02	1 303 at 59°F

2 2 3 General Discussion of Simulant Selection Program

Using a mixture of the gases the Chemical Equilibrium Composition computer program (CEC) Ref 18, calculates the thermodynamic properties of the mixture Then utilizing a modified source flow model, the momentum flux and Mach number at a specified point in the plume are compared to those produced by the real gas under prototype conditions also in a modified source flow plume In addition, the Reynold's number at the exit plane is computed to ensure that the boundary layer effect is similar The boundary layer calculation is discussed later, however, the most important point to note is that automating the computations allows possible gas mixtures to be thoroughly searched Thus not only can the mixture ratio be varied, but the stagnation pressure and temperature can be altered within specified limits Unfortunately, if one particular gas mixture does not meet the desired specifications, another set of gases must be tried at random However, this is the same procedure employed in Ref 1, and no real alternative appears to be available After a set of gases is chosen for a specified chamber temperature and pressure, it is possible to determine rather quickly if any possible combination will meet the desired criteria This calculation is described in detail in Appendix A

Thus, after a possible gas mixture has been selected, the ability of this gas to simulate forces on a body immersed in a plume formed from these gases must be predicted This can be done by use, again, of a source flow model of the plume

- Plume Source Flow Model

As illustrated in Fig 1 taken from Ref 12, the flow field computed by a source flow model predicts quite well the parameters of the far flowfield region Since real gas effects are to be included in the analysis, the technique of Ref 12 discussed in Section 2 1 could not be used to obtain a closed

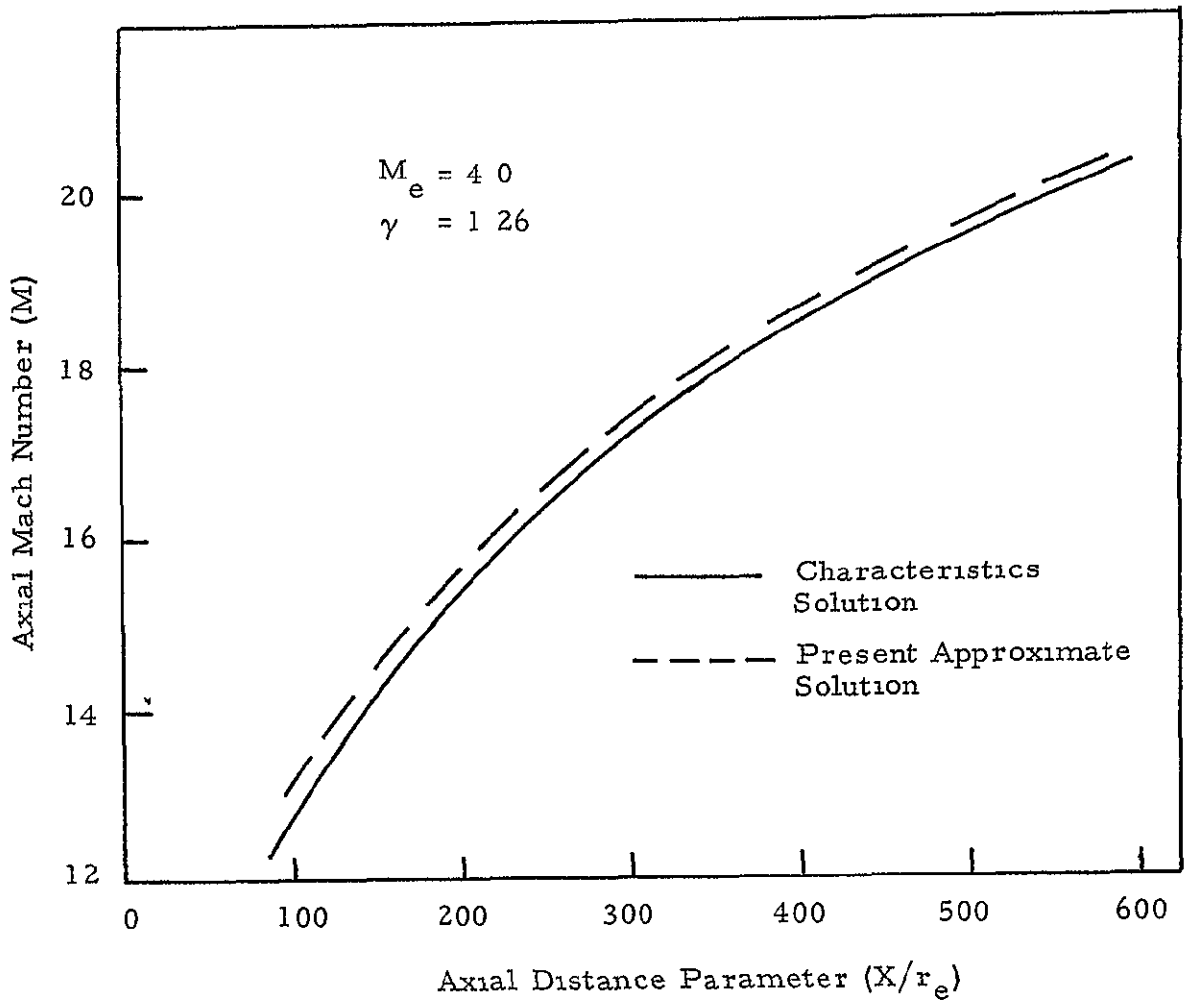


Fig 1 — A Comparison of the Approximate and Characteristics Solution for a Rocket Exhausting into a Vaccum (M_e = 4 0, γ = 1 24) Ref 12

form solution for the flow properties at a point Instead, a numerical solution using the method of false position was employed to solve for the flow field properties that satisfied the specified area ratio of the flow field In addition, rather than assuming a hemispherical flow field as Ref 12, the Prandtl-Meyer expansion angle at the nozzle lip is computed and the area ratio of the plume is calculated using this as the boundary of the plume (Fig 2) Reference 13 discusses this program more fully The centerline Mach numbers for the RIE exhaust plume as computed by the MOC and source flow programs are shown in Fig 3 taken from Ref 13 Once again the comparison is acceptable

After the plume is generated, corresponding points of the model and prototype plume flow fields can be compared The technique thus produces a flexible but bulky method of determining a good simulant mixture It should be noted, however, that not only must points in the inviscid plume be compared, but also viscous effects in the nozzle which are similar must be ensured

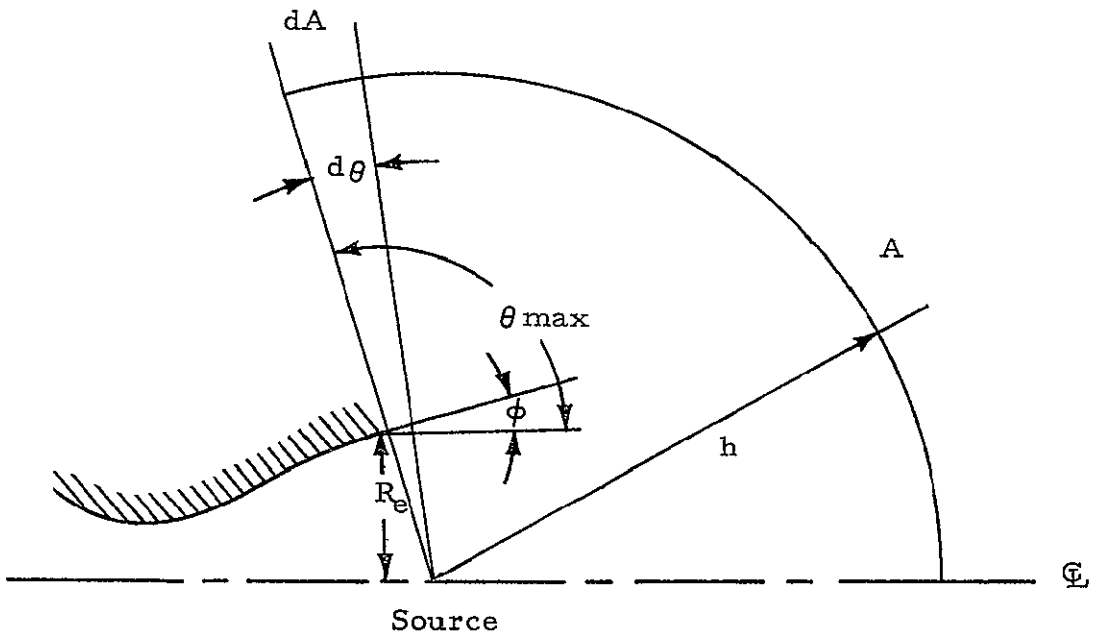
- Boundary Layer

To simulate the viscous flow effects in the nozzle the ratio, δ/D, must be equal for both model and prototype The following analysis is carried out assuming turbulent flow in the nozzle Similar statements can be made regarding laminar flow In general the boundary layer thickness can be written as a familiar function of Reynolds number

$$\delta/\ell = k\left(\frac{\rho u \ell}{\mu}\right)^{-1/5} = k\left(R_\ell\right)^{-1/5} \qquad (28)$$

where k is a constant for turbulent flow and R_ℓ is Reynolds number based on a characteristic length of the nozzle Now obtaining a ratio of (δ/D)

$$\left(\frac{\delta}{D}\right)\frac{1}{\ell} = \frac{k}{d^{4/5}\,\ell^{1/5}}\left(\frac{1}{R_D}\right)^{1/5}$$



θ_{max} = Prandtl -Meyer Expansion Angle

ϕ = Nozzle Lip Angle

Fig 2 - Source Flow Model of Plume Showing the Model Geometry

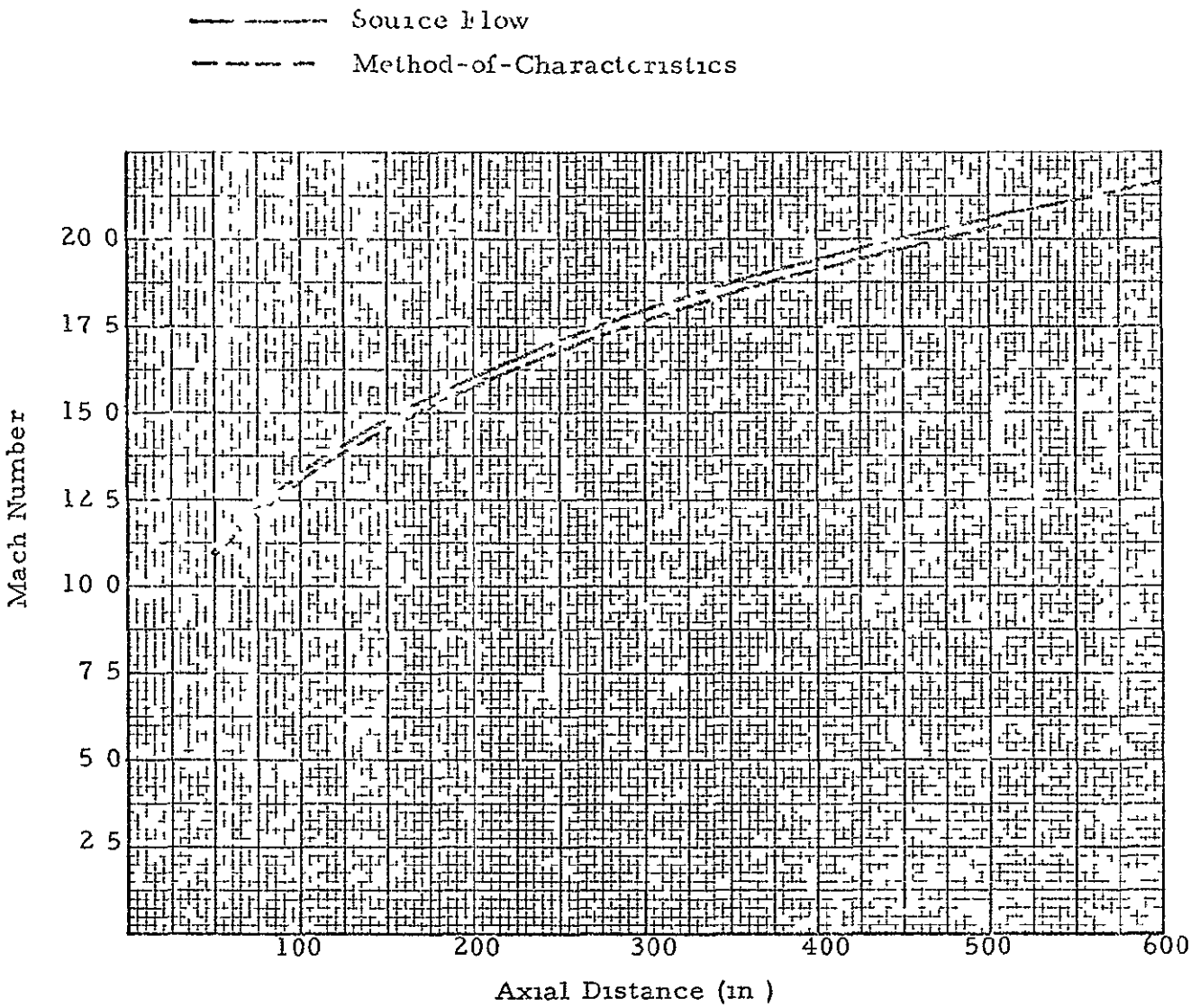


Fig 3 - Comparison of the R-1E Engine Centerline Distribution of Mach Numbers Using Data from the Method-of-Characteristics and Source Flow Computer Programs (γ = 1 259)

or

$$\left(\frac{\delta}{D}\right) = k\left(\frac{\ell}{D}\right)^{4/5}\left(\frac{1}{R_D}\right)^{1/5} \tag{29}$$

Equating the ratio for model and plume cases

$$k\left(\frac{\ell}{D}\right)^{4/5}\left(\frac{1}{R_D}\right)^{1/5}\Bigg|_m = k\left(\frac{\ell}{D}\right)^{4/5}\left(\frac{1}{R_D}\right)^{1/5}\Bigg|_p$$

Thus

$$\left(\frac{\ell}{D}\right)^{4/5}\left(\frac{1}{R_D}\right)^{1/5}\Bigg|_m = \left(\frac{\ell}{D}\right)^{4/5}\left(\frac{1}{R_D}\right)^{1/5}\Bigg|_p \tag{30}$$

Now if Reynolds number can be duplicated, then near geometric similarity assures similitude However, from Refs. 1 and 2 it may be difficult to duplicate Reynolds number In order to ensure viscous similarity it may be necessary to modify the length of the model nozzle, or

$$\ell_m^{4/5} = \left(\frac{D_m}{D_p}\right)^{4/5} \ell_p \left(\frac{R_{D_p}}{R_{D_m}}\right)^{1/5}$$

$$= (SF)^{4/5} \ell_p^{4/5} \left(\frac{R_{D_p}}{R_{D_m}}\right)^{1/5}$$

$$\ell_m = (SF) \ell_p \left(\frac{R_{D_p}}{R_{D_m}}\right)^{1/4} \tag{31}$$

In the present study the primary concern is that the boundary layer shall be no greater in the model situation than in the prototype situation To meet this requirement, the simulant selection program specifies that the Reynolds number of the model must be equal to or greater than the Reynolds number of the prototype nozzle Transport properties of the gases in question are computed, using the methods reported in Ref 19

For the sake of completeness, a modified nozzle length can be calculated after a gas mixture has been established for a specified chamber condition Besides simulating the basic flowfield parameters (such as Mach number and Reynolds number) one other phenomenon, condensation, must be matched

- Condensation

Generally, in highly expanded rocket plumes having temperatures well below 100°K, heterogeneous systems are of considerable importance In particular, as the partial pressure of each gaseous component drops below its vapor pressure, the probability of the formation of liquid droplets increases In general, the theory of condensation is felt to be understood In fact, calculations of condensation in steam nozzles or of water vapor in air seem to bear out this theory See for example Refs 20 and 21 Unfortunately, corresponding calculations cannot be as easily made for the gaseous substances such as nitrogen or carbon dioxide Much of the problem lies in the lack of accurate knowledge of material properties such as surface tension and density The problem may be illustrated by writing the expression for fractional formation rates (Ref 20)

$$\frac{1}{Ng}\frac{dNg}{dT} = g^* \frac{J(g^*)}{Ng} = \frac{P}{kT}\frac{4r_d^{*3}}{3}\sqrt{\frac{2\pi\zeta}{m}}\, e^{-4\pi\zeta r_d^{*2}/3kT} \tag{32}$$

The dominant term in the expression is the exponential

$$e^{-4\pi\zeta r_d^{*2}/3kT} \tag{33}$$

which may be written

$$e^{-16\pi\zeta^3 V_{liq}^2/3(kT)^3 \ln\left(P/P_{s_\infty}\right)} \tag{34}$$

Since surface tension ζ is a cubed quantity, any error in it greatly alters the computed condensation rate

Because of this problem, no attempt was made to match condensation rate Rather, an attempt was made to duplicate only the location of condensation Currently condensation is assumed to occur when the partial pressure of the gaseous species drops below the vapor pressure for that corresponding temperature The point at which condensation occurs is modified by adjusting the chamber temperature Since this adjustment could upset simulation of impingement forces or viscous effects, it is carried out last Noncompliance with the condensation requirement does not eliminate the gas mixture, however, the search is continued for other combinations that might better duplicate the prototype flow field

This concludes a brief description of the approach taken to simulate a plume flow field Obviously some differences exist between the model and prototype condition In order to analytically scale from the model to the prototype condition the following approach is used

2 2 4 Scale Factors

After a gas mixture and chamber condition have been selected, the veracity of the choice must be tested In order to transfer analytically from the model to the prototype case, a scale factor is defined Although the methods of Ref 4 were considered for use, a much simpler analytical correlation between the prototype and model cases is supplied by comparing the momentum flux in the corresponding plume regions This factor thus corrects for mismatches of any pertinent parameters The correction factor for momentum is designated as β where

$$\beta = \frac{(\text{momentum flux})_p}{(\text{momentum flux})_m} \tag{35}$$

This concludes the description of the method of analysis. A discussion now follows of the results obtained thus far with the simulant selection computer program

2 3 DISCUSSION OF ANALYTICAL RESULTS

Table 2 compares the operating characteristics for a prototype rocket motor and its corresponding model nozzle For this case, the simulant gas mixture was a gaseous binary mixture Since the simulant mixture was binary, condensation was not accounted for Significantly, with the higher operating pressure of the model case, the exit plane Reynolds number was higher than the prototype case Thus the boundary layer should be at least no greater a factor in the model case than in the prototype case The ability to minimize the importance of the boundary layer for both the binary and ternary simulant mixtures greatly facilitates a search for a suitable simulant mixture The centerline Mach number distribution is compared for the prototype and model case in Fig 3 The error in the momentum flux at the center of the region of interest is 2%. Thus impingement forces in this region should be very closely scaled

Again Table 2 compares the operating parameters for another prototype nozzle and its correspondent model nozzle. Now, the simulant gas was a gaseous ternary system The additional gas CO_2 was assumed to be a condensable gas in the model system Once again it was possible to minimize the boundary layer effect in the model case

A rather surprising result occurred when the point of condensation or point of vapor saturation in the model and prototype plume was computed For both cases, the point of condensation was found to occur far out in the plume Realistically, this result may be more a reflection of the calculational methods used than of the physical situation However, since the prototype and model calculations are independent, it appears significant that this result was obtained for both cases Figure 3 compares the centerline Mach

Table 2

COMPARISON OF MODEL AND PROTOTYPE ENGINE OPERATIONAL CHARACTERISTICS

Engine	Binary Mixture			Ternary Mixture		
	Gases	Percent	Chamber Pressure (psia)	Gases	Percent	Chamber Pressure (psia)
Model	CF_4	0 6405	200	CF_4	0 7151	200
	N_2	0 3595		N_2	0 0849	
				CO_2	0 2000	
Prototype	Fuel C_2H_4	0.5	100	Fuel CH_3NHNH_2	0 5	100
	Oxidant O_2	0 5		Oxidant N_2O_4	0 5	

number distribution for the model and prototype case The error in the momentum flux at the center of the region of interest is 3% Because of time limitations the two sample cases were the only results obtained to date However, some general comments may be made concerning the simulant selection program

First, the program is quite fast. The two cases discussed above were executing in approximately 5 to 6 minutes on the IBM 7094 From work performed while the program was being checked out, it appears that if new gases must be selected, then the run time will approximately double. Thus, it does appear that this computer program is a practical and economical tool to use in the design of an experiment to test impingement forces on bodies immersed in a plume

A result of perhaps a more serious nature occurred for the ternary case Here with a mixture of CF_4, N_2 and CO_2 at elevated temperatures, some decomposition and reaction of the gases was predicted by the CEC routines One of the resultant gases was COF_3 This gas is quite toxic, being related to phosgene, the nerve gas Although mixtures of CF_4 and CO_2 were used in Ref 3, this mixture should not be used in a practical experimental situation until a thorough study of reaction rates is made Suitable substitutes for CF_4 might be the inert gases such as neon, krypton and xenon Krypton and xenon are rather expensive, but they are becoming more commonplace. Only neon exists on the products tape to date, however, if necessary, the others could be readily included

Section 3
CONCLUSIONS AND RECOMMENDATIONS

In general, simulation of rocket exhaust plumes and the subsequent impingement force can be attained by using nonreacting gas mixtures in model nozzles A computer program which performs the arduous task of selecting a suitable simulant gas mixture has been written and checked out Although several options are available, the most important consists of selecting a simulant gas based upon its ability to duplicate momentum flux or impingement force on a body immersed in a plume A set of gases was established which, when mixed, provide good simulation properties Data for these gases are stored on magnetic tape Additional gases can be added to the tape when deemed desirable For the two test cases examined, simulant gases were obtained that duplicated the prototype case very well

Since in an experimental situation it may be difficult with available equipment to attain the necessary parameters for exact simulation, an experimental program to examine the effects of nonsimilarity is recommended Such a program was outlined in Ref 22 In brief, by operating a single nozzle at several chamber conditions, the variation in impingement force with chamber enthalpy may be ascertained Then, using two scaled nozzles — one as model and the other as prototype — the simulant selection program will be used to select a gas mixture for the model Using this gas mixture in the model, impingement forces on a submerged body will be measured and compared to those for the prototype case Facilities exist to carry out such a study and such an investigation would add validity to the analytical results developed in the current contract

Before concluding this report this speculative note will be advanced In order to duplicate the flow field of a gas the properties of the model gas

must be known There is at this time some preliminary effort to use numerical techniques on electronic computers to solve the equations of quantum mechanics for various molecules (Ref 23) With techniques of this type available, a tremendous number of possible molecules could be studied and their resultant thermodynamic properties predicted Thermodynamic properties of these molecules could then be compared with the properties of the molecules of the prototype nozzle, and a simulant gas could be selected on the basis of this comparison Although such a study was beyond the state-of-the-art for the current effort, these techniques might be considered in future efforts

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APPENDIX A

EFFECT OF MIXTURE RATIO ON MACH NUMBER

Appendix A

The goal of this analysis is to determine if, for specified chamber conditions, any combination of a set of gases can duplicate the conditions at a point in the prototype plume If duplication is possible, the mixture ratio which will produce the desired conditions must be computed

Although this search could be made simply by modifying the mixture ratio and observing the resultant change, the ability to make an intelligent estimate concerning the amount of change required is desirable The estimate need not be exact, it merely points the iteration process in the correct direction and supplies a rough figure for the amount of change necessary in the gas mixture, given the chamber conditions Now the simulant gas will be selected by its ability to match Mach number and momentum Appendix B shows that for large values of Mach number, the rate of change of pressure is small compared to the rate of change of Mach number Hence, the change in momentum becomes a strong function of Mach number

To determine the mixture ratio, the equations of motion are employed with the definition of Mach number, all written in differential form In this manner, when the initial mixture ratio is known, the necessary change in mixture ratio can be computed Before proceeding with the analysis note that mixture ratio can be related to mean molecular weight of a mixture Thus, molecular weight of the mixture is used as a variable in the following analysis In the computer program, this is related back to mixture ratio With this in mind the variation of flow parameters is formulated for one-dimensional flow

The following assumptions are made

a Flow is one-dimensional and steady

b Changes in stream properties are continuous

c Gas is semi-perfect, specific heat varies with composition and temperature

Writing the basic equations in differential form,

Equation of State

$$\frac{dP}{P} = \frac{d\rho}{\rho} + \frac{dT}{T} - \frac{d\psi}{\psi} \qquad A\ 1$$

Continuity

$$\frac{d\dot{m}}{m} = \frac{d\rho}{\rho} + \frac{du}{u} + \frac{dA}{A} \qquad A\ 2$$

Energy

$$\frac{1}{C_p T}\ \frac{d\dot{m}}{m} + \frac{1}{h_o}\left(\frac{dh}{C_p T} + \frac{\gamma - 1}{2} M^2 \frac{du^2}{u^2}\right) = 0 \qquad A\ 3$$

Momentum

$$\frac{dP}{P} + \gamma M^2 \left(\frac{dA}{A} + \frac{du^2}{u^2} + \frac{d\rho}{\rho}\right) = 0 \qquad A\ 4$$

and the definition of Mach number

$$\frac{dM^2}{M^2} = \frac{du^2}{u^2} + \frac{d\psi}{\psi} - \frac{d\gamma}{\gamma} - \frac{dT}{T} \qquad \text{A 5}$$

Now Eq (A 5) is rewritten

$$\frac{d\psi}{\psi} = \frac{dM^2}{M^2} - \frac{du^2}{u^2} + \frac{d\gamma}{\gamma} + \frac{dT}{T} \qquad \text{A 6}$$

And Eqs (A 1) through (A 4) are then used to write du^2/u^2, $d\gamma/\gamma$, and dT/T in terms of M and ψ

The equation obtained after all the algebraic manipulation is

$$\frac{d\psi}{\psi} = \frac{dM^2}{M^2} - 2\left\{-\frac{h}{h_o}\left[\frac{dh}{h} - \frac{\gamma-1}{2} M^2\left(\frac{dT}{T} - \frac{d\psi}{\psi}\right) - \frac{dA}{A}\right]\right.$$

$$\left. + \frac{dh}{h} - \frac{d\psi}{\psi} - \frac{dA}{A}\right\} + \frac{d\gamma}{\gamma} + \frac{dh}{h} \qquad \text{A 7}$$

Where h has been substituted for $C_p T$ to simplify the equation slightly

Now assume that h and γ are linear functions of ψ or molecular weight Although this is not true, the assumption can be shown to yield results which are in error a maximum of 5 to 10% See Figs A-1 and A-2 and refer to Ref 2 Changes in γ and h may then be expressed as

$$dh = m_1 \, d\psi \qquad \text{A-8a}$$

$$d\gamma = m_2 \, d\psi \qquad \text{A-8b}$$

The expression for the change in molecular weight or mixture ratio required to produce a desired change in Mach number becomes

$$d\Psi = \frac{dM^2}{M^2} \Bigg/ \left[\frac{1}{\Psi} + \frac{2h}{h_o} \left\{ -\frac{m_1}{h} + \frac{\gamma-1}{2} M^2 \left(\frac{m_1}{h} - \frac{1}{\Psi} \right) + \frac{dA}{A} \right\} \right.$$

$$\left. + \frac{2\,m_1}{h} - \frac{2}{\Psi} - \frac{2dA}{A} - \frac{m_2}{\gamma} - \frac{m_1}{h} \right] \qquad \text{A 9}$$

Now an expression for dA/A can be obtained easily by assuming an inviscid expansion at the nozzle lip and computing the change in the Prandtl-Meyer expansion angle caused by changing the gas composition Since the nozzles under consideration in this study have large area ratios (A/A^*), assume that the gas in expansion is frozen thermodynamically The limiting expansion angel can then be expressed,

$$\nu = \frac{\pi}{2} \left[\sqrt{\frac{\gamma+1}{\gamma-1}} - 1 \right] \qquad \text{A 10}$$

Or θ, the flow, angle can be written

$$\theta = \nu - \nu_e + \phi \qquad \text{A 11}$$

then the one-dimensional area of the plume at some radial distance S from the source is,

$$A = S\ \theta \qquad \text{A 12}$$

Now with a small change in gas composition or γ the resultant area change is approximated by

$$dA = S d\theta = S \left[d\nu - d\nu_e \right] \qquad \text{A 13}$$

$$\nu_e = \sqrt{\frac{\gamma+1}{\gamma-1}} \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1}\left(M_e^2 - 1\right)} - \tan^{-1} \sqrt{M_e^2 - 1} \qquad \text{A 14}$$

$$d\nu = -\frac{1}{(\gamma-1)^2} \frac{\pi}{2} \sqrt{\frac{\gamma-1}{\gamma+1}}\, d\gamma \qquad \text{A 15}$$

$$d\nu_e = -\frac{1}{(\gamma-1)^2} \sqrt{\frac{\gamma-1}{\gamma+1}} \tan^{-1} \sqrt{\frac{\gamma-1}{\gamma+1}\left(M_e^2 - 1\right)} +$$

$$2 \sqrt{\frac{\gamma+1}{\gamma-1}} \left(M_e^2 - 1\right) \Bigg/ \left[1 + \frac{\gamma-1}{\gamma+1}\left(M_e^2 - 1\right)\right] \left[\frac{1}{2} \frac{\gamma-1}{\gamma+1}\left(M_e^2 - 1\right)\right]^{1/2} d\gamma \qquad \text{A 16}$$

$$\frac{dA}{A} = \frac{(d\nu - d\nu_e)\, d\gamma}{\theta} \qquad \text{A 17}$$

This expression for dA/A can then be substituted into Eq A 9 to complete the analysis Obviously, the final expression is not strictly correct, however, it does allow an estimate of the change required in gas mixture to obtain the desired parameter

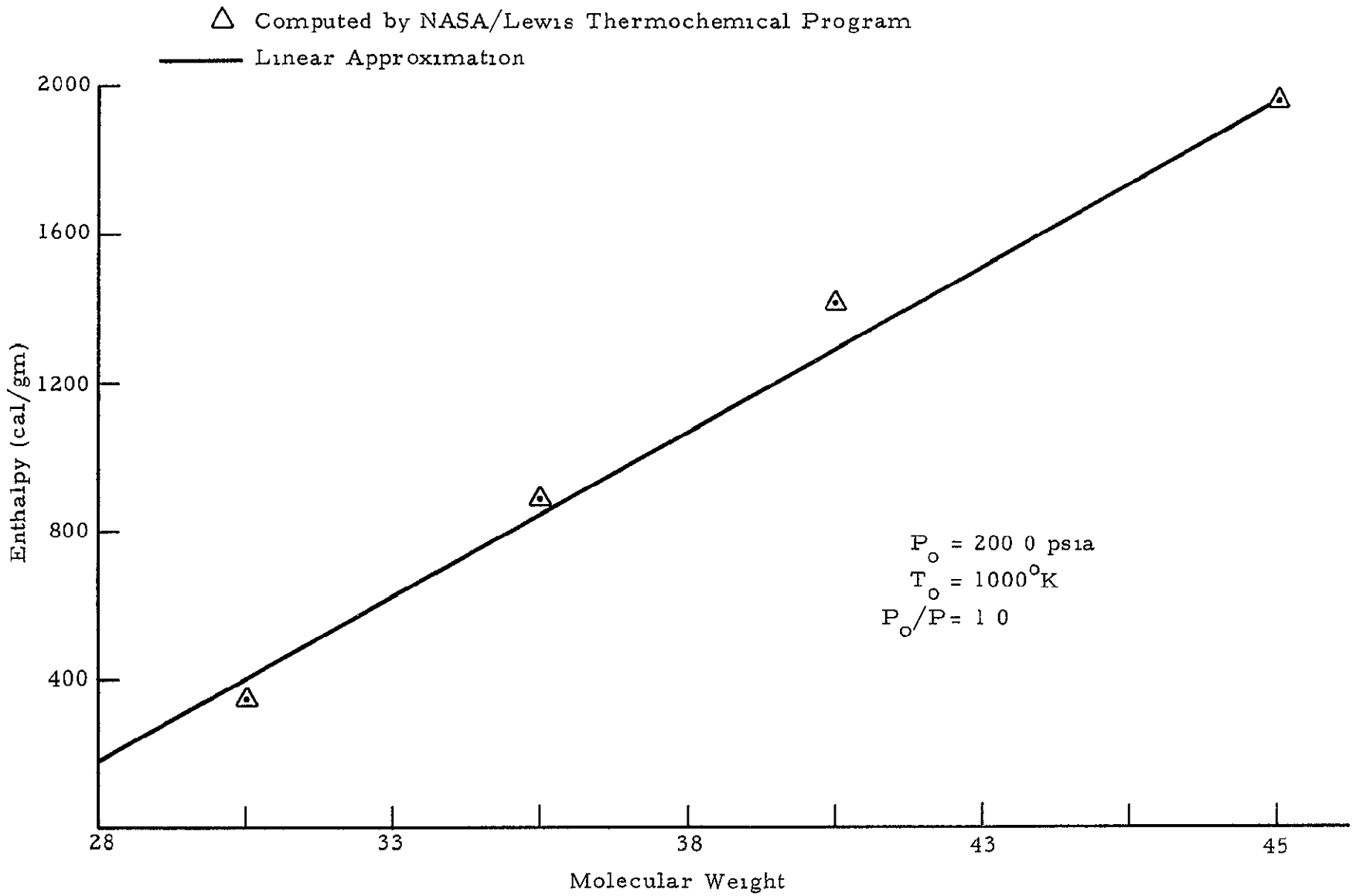

Fig A-1 - Enthalpy Versus Molecular Weight for Various Mixtures of Gaseous Nitrogen and Carbon Dioxide

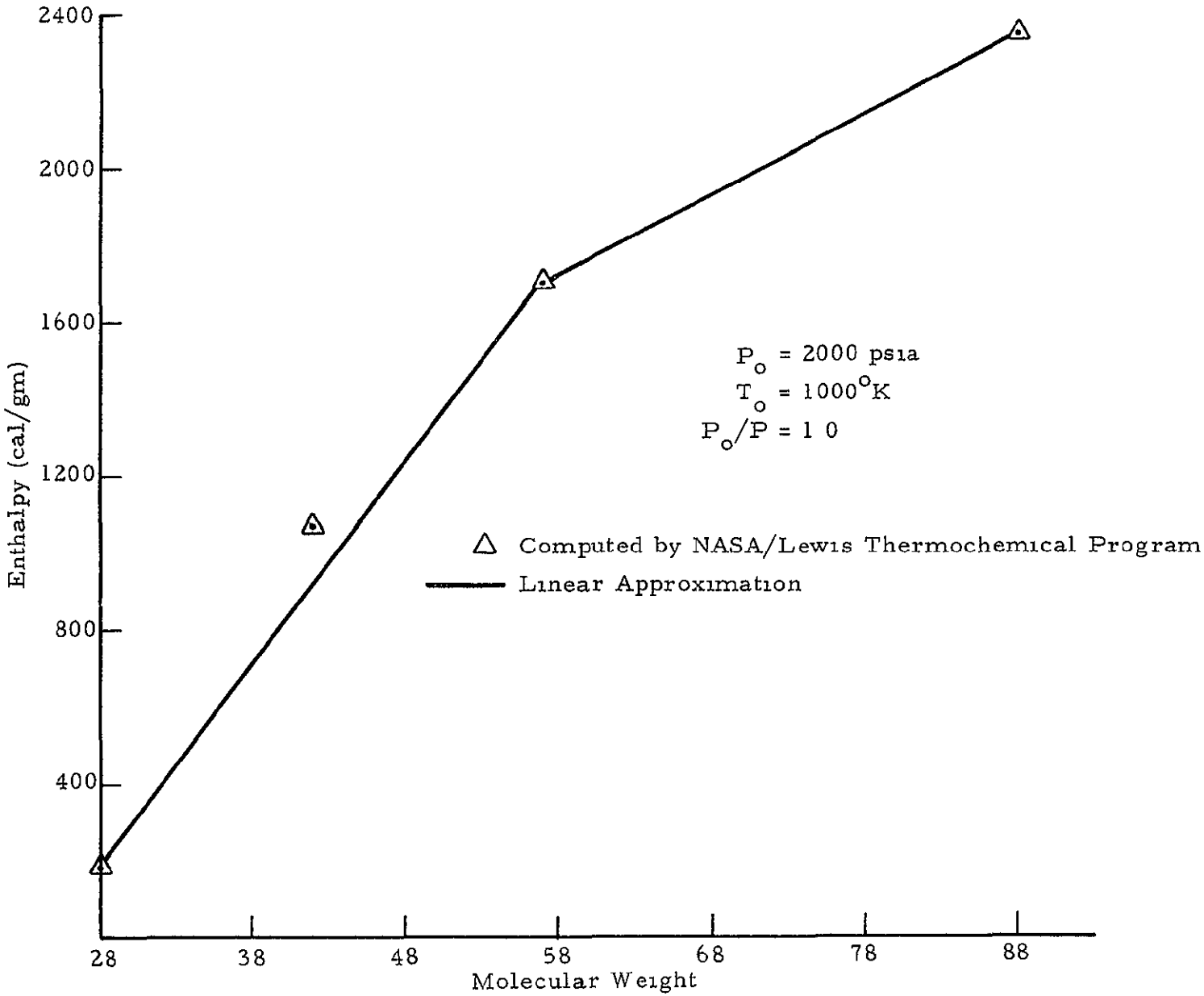

Fig A-2 - Enthalpy Versus Molecular Weight for Various Mixtures of Gaseous Nitrogen and Carbon Tetrafluoride (CF_4)

APPENDIX B

ISENTROPIC EXPANSION IN TERMS OF THE VARIABLES PRESSURE AND MACH NUMBER

Appendix B

Assuming isentropic conditions hold at a point, then we may write

$$P = P_o \Big/ \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\gamma/\gamma-1} \qquad \text{(B-1)}$$

Now let M change by an amount ΔM Then

$$\Delta P = \frac{P_o}{\left[1 + \frac{\gamma - 1}{2}\left(M^2 + 2\,M\Delta M + (\Delta M)^2\right)\right]^{\gamma/\gamma-1}} \frac{P_o}{\left(1 + \frac{\gamma-1}{2} M^2\right)^{\gamma/\gamma-1}} \qquad \text{(B-2)}$$

assuming some typical values for P_o, M and γ in an expanded plume,

$$P_o = 1000$$
$$\gamma = 1.4$$
$$M = 20$$

Then for a 10% change in M,

$$\Delta P = 0\ 059 \times 10^{-3}$$

Since ΔP is an inverse function of M, it obviously becomes greater for smaller Mach numbers However, the region of interest in this project is the highly expanded region and in that case changes in pressure are small for changes in Mach number

APPENDIX C

USER'S MANUAL

DESCRIPTION OF A DIGITAL COMPUTER PROGRAM FOR SELECTING A GAS MIXTURE TO SIMULATE THE PLUME OF A ROCKET NOZZLE

Appendix C

C.1 INTRODUCTION

To determine accurately impingement forces on complex bodies immersed in the plume of a rocket nozzle experimental testing on scale models of the prototype situation is needed To simplify the experimental procedure nonreacting cold gases should be used to simulate the plume If cold nonreacting gases are introduced in the test situation, duplication of the entire prototype plume is impossible and selecting a simulant gas mixture becomes difficult

To overcome the numerical magnitude of selecting the simulant, Lockheed Missiles & Space Company, Huntsville Research & Engineering Center, developed under contract to the Aero-Astrodynamics Laboratory of Marshall Space Flight Center, a digital program which rapidly searches among possible simulant gases to determine a gas mixture that best approximates a region in the prototype plume The program is applicable for problems involving the high altitude expansion of a nozzle exhaust Input to this program has been kept as simple as possible in order to enhance the usefulness of the program

This document was prepared to facilitate operation and understanding of the program Questions involving initial assumptions made in this program can be answered by referring to the main body of this report Inevitably questions will arise concerning any newly created program These should be referred to the author

C 2 DISCUSSION

The program consists of 28 active subroutines or functions which perform the gas thermodynamic calculations, the source flow expansion and the comparison of prototype and model plumes. A general flow chart of the method of solution is given in Figure C-1 In addition, the overlay structure necessary for use on the IBM 7094 computer is illustrated in Fig C-2

The Input procedure and output interpretation is covered in the Input/Output Section The input instructions are simple and self-explanatory The output instructions are in the form of flagged comments which refer to a corresponding section on a typical page of output An IBM 7094 Instruction card is included at the end of the Input/Output Section

To aid in the study of this program a commented listing of the program is included in this document as Appendix D

Table 1 of the basic report tabulates the gases which are currently stored on the master tape as possible simulant gases. This array can be expanded using results from Refs 17 or 18

Table C-1 (From Table 1)

Gases Currently Available for Analysis as Possible Simulants	
Ar	Argon
$CClF_3$	Carbon Chlortrifluoride
CF_4	Carbon tetrafluoride
CHF_3	Trifluormethane
CO_2	Carbon dioxide
H_2	Hydrogen
N_2	Nitrogen
N_2O	Nitrous oxide

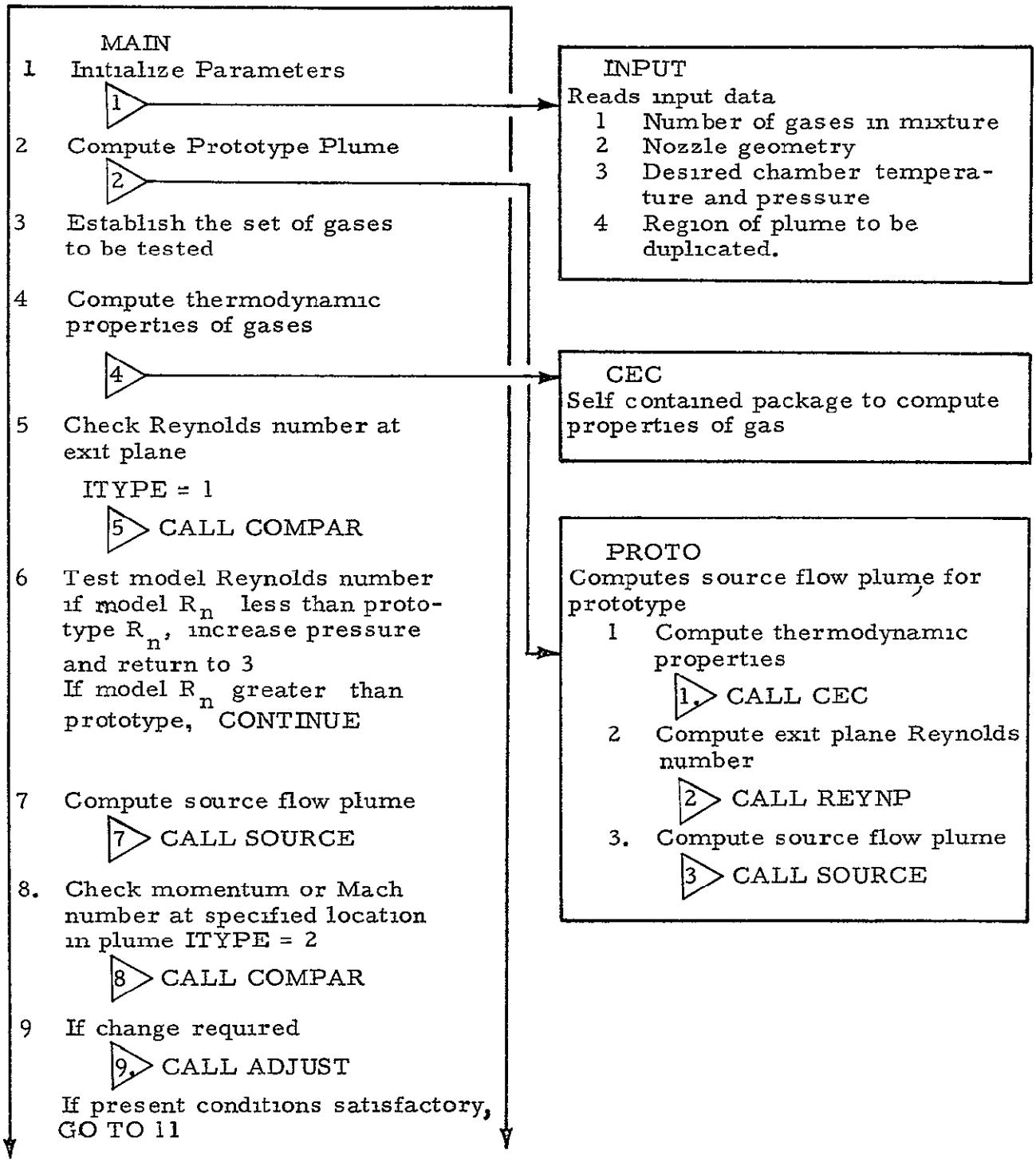

Fig C-1 — General Flow of Program

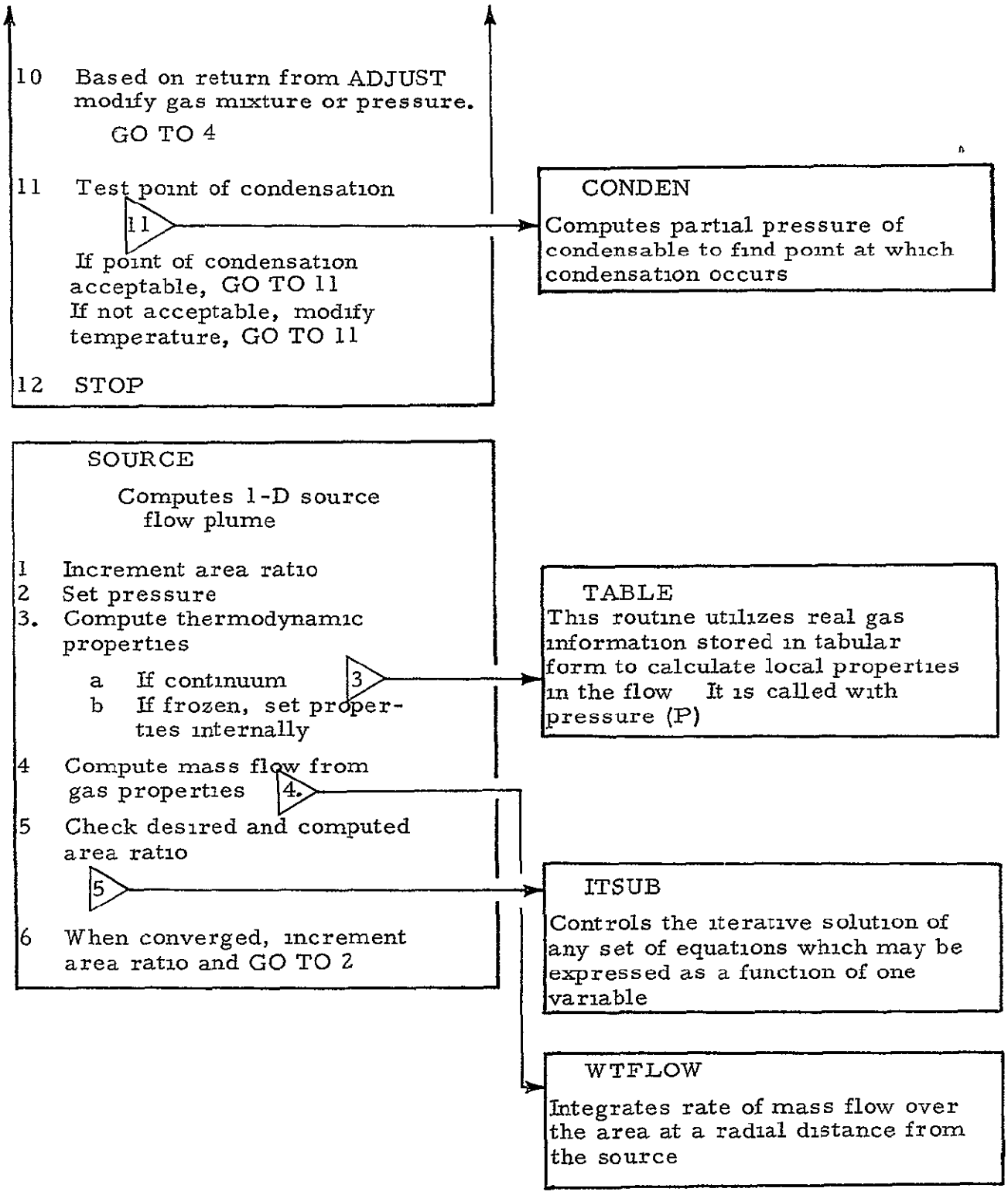
10 Based on return from ADJUST modify gas mixture or pressure.
GO TO 4
11 Test point of condensation
11
If point of condensation acceptable, GO TO 11
If not acceptable, modify temperature, GO TO 11
12 STOP
CONDEN
Computes partial pressure of condensable to find point at which condensation occurs
SOURCE
Computes 1-D source flow plume
1 Increment area ratio
2 Set pressure
3. Compute thermodynamic properties
a If continuum
b If frozen, set properties internally
3
4 Compute mass flow from gas properties
4.
5 Check desired and computed area ratio
5
6 When converged, increment area ratio and GO TO 2
TABLE
This routine utilizes real gas information stored in tabular form to calculate local properties in the flow It is called with pressure (P)
ITSUB
Controls the iterative solution of any set of equations which may be expressed as a function of one variable
WTFLOW
Integrates rate of mass flow over the area at a radial distance from the source

Fig C-1 Contd

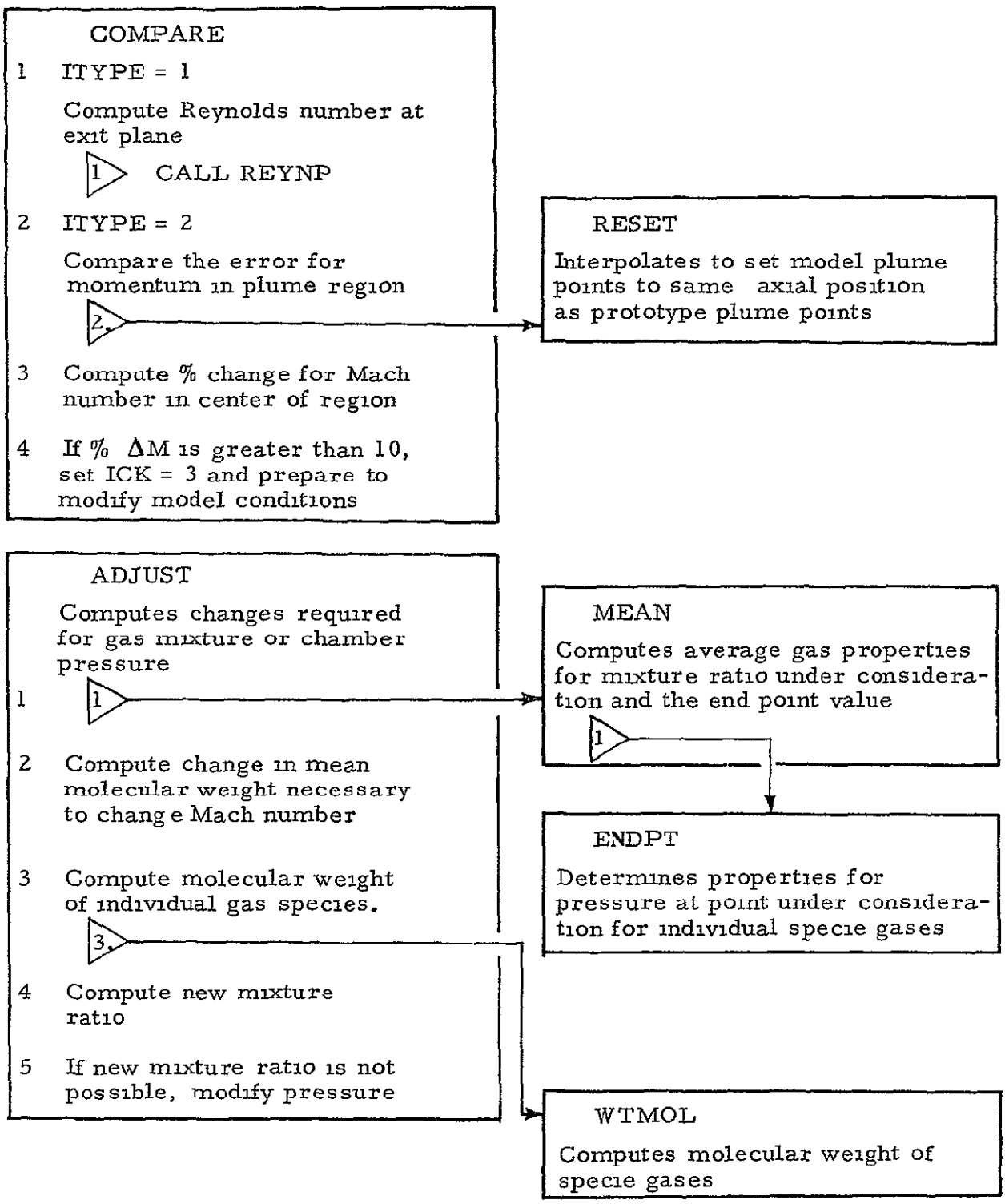
COMPARE
1 ITYPE = 1
Compute Reynolds number at exit plane
1
CALL REYNP
2 ITYPE = 2
Compare the error for momentum in plume region
2
3 Compute % change for Mach number in center of region
4 If % ΔM is greater than 10, set ICK = 3 and prepare to modify model conditions
RESET
Interpolates to set model plume points to same axial position as prototype plume points
ADJUST
Computes changes required for gas mixture or chamber pressure
1 1
2 Compute change in mean molecular weight necessary to change Mach number
3 Compute molecular weight of individual gas species.
3
4 Compute new mixture ratio
5 If new mixture ratio is not possible, modify pressure
MEAN
Computes average gas properties for mixture ratio under consideration and the end point value
1
ENDPT
Determines properties for pressure at point under consideration for individual specie gases
WTMOL
Computes molecular weight of specie gases

Fig. C-1 Contd

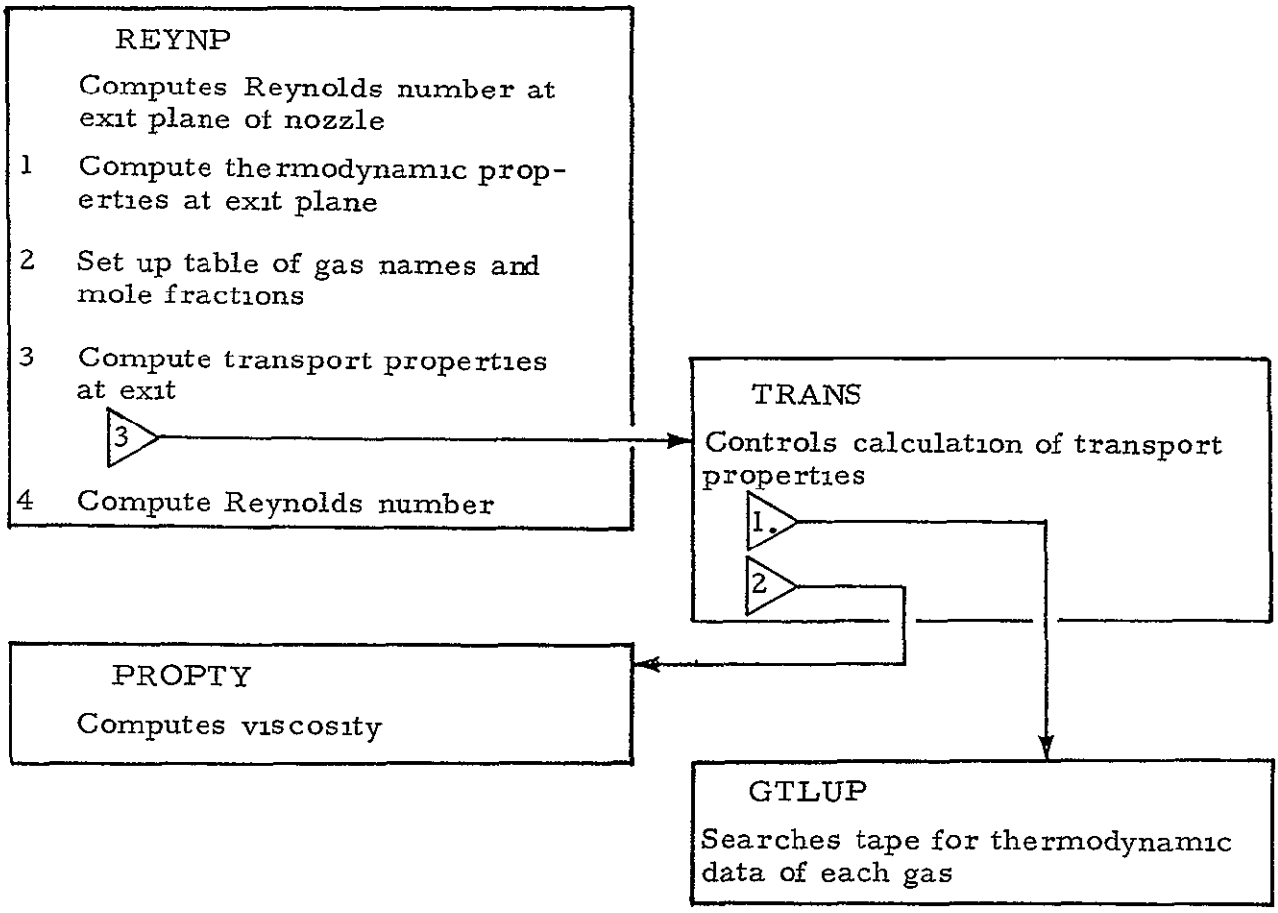
REYNP
Computes Reynolds number at exit plane of nozzle
1 Compute thermodynamic properties at exit plane
2 Set up table of gas names and mole fractions
3 Compute transport properties at exit
3
4 Compute Reynolds number
TRANS
Controls calculation of transport properties
1.
2
PROPTY
Computes viscosity
GTLUP
Searches tape for thermodynamic data of each gas

Fig C-1 Contd

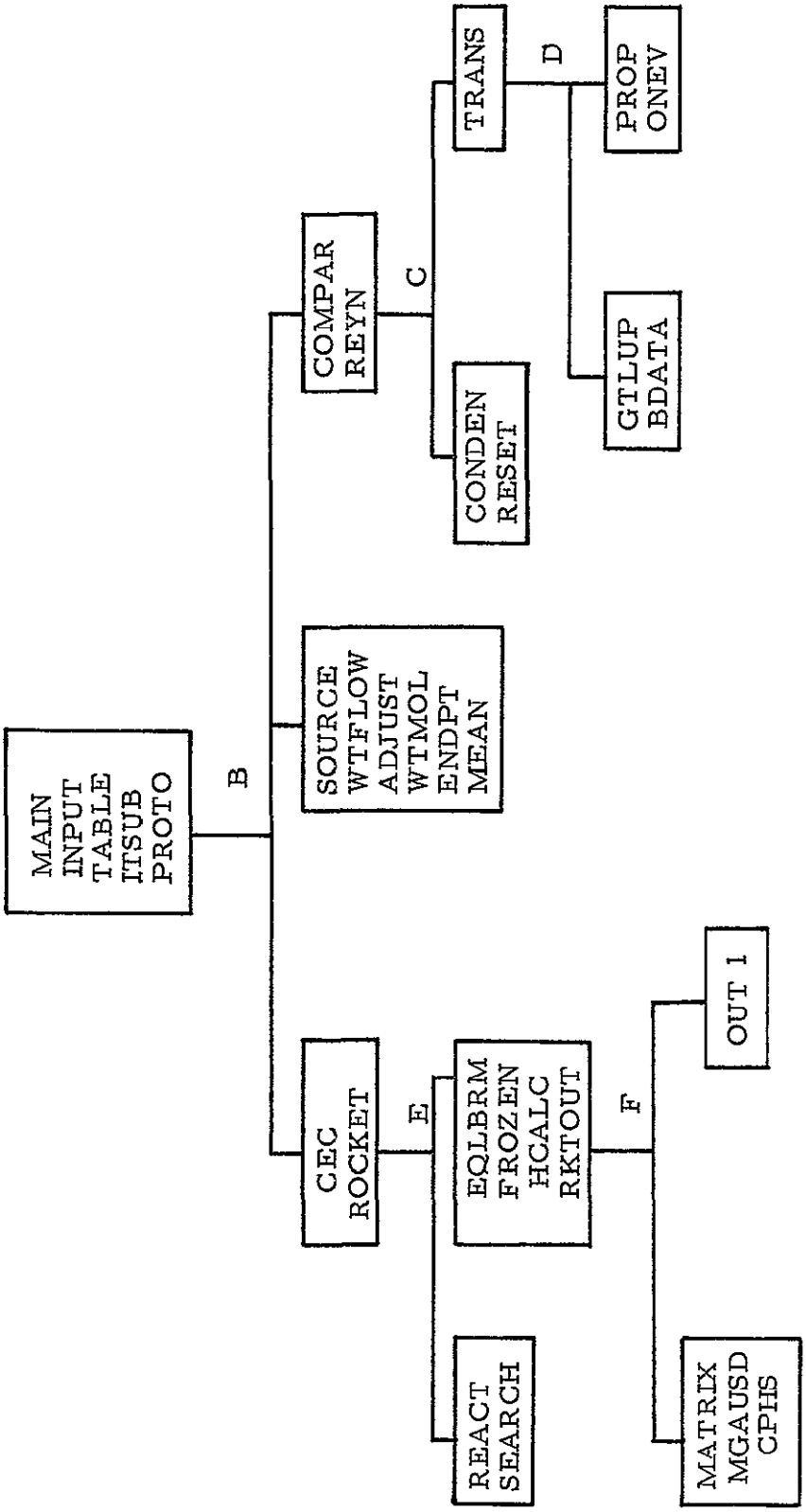

Fig C-2 -- Overlay Structure of Simulant Selection Program

C 2 1

INPUT GUIDE

CARD NO 1		Problem Title or Identification
FORMAT	12A6	
Cols 1 - 72	HOL	Comment card or header information
CARD NO 2	Control	Card
FORMAT	8I5	
Cols 1 - 5	NMIX	Number of gases to be used in simulant mixture
Cols 6 - 10	NPTS	Number of points in plume to be matched Must be 3
Col 11 - 15	IP	O Set initial chamber pressure in program
		1 Read in initial chamber pressure
Col 16 - 20	IT	O Set initial chamber temperature in program
		1 Read in initial chamber temperature
Col 21 - 25	IG	O Gases to be selected by program
		1 Specific gas mixture to be read in
Col. 26 - 30	IFLAG	O Regular output
		1 Intermediate output for debugging model information
Col 31 - 35	ITYPE	1 Calculation of simulation ability to be based on momentum flux comparison
		2 Calculation of simulation ability to be based on Mach number comparison
		3 Calculation of simulation ability to be based on Reynolds number comparison
CARD NO 3		
FORMAT	7E10 6	

Col 1 - 10	ATM	Nossle throat area of model
Col 11 - 20	RADTHM	Throat radius of model (ft)
Col 21 - 30	AEOATM	Ratio of exit plane area to throat area of model
Col 31 - 40	ANGLPM	Angle at nozzle lip of model (deg)
CARD NO 4	(Included if either chamber pressure or temperature is to be specified)	
FORMAT	7E10 6	
Col 1 - 10	PCHAMI	Model chamber pressure to be initially used Blank if not applicable (PSI)
Col 11 - 20	TCHAMI	Model chamber temperature to be initially used Blank if not applicable (deg R)
CARD NO 5	Prototype Information	
FORMAT	7E10 6	
Col 1 - 10	RADP	Throat radius of prototype nozzle
Col 11 - 20	AETP	Ratio of exit plane area to throat area for prototype
Col 21 - 30	ANGP	Angle at exit plane of prototype nozzle (deg)
Col 31 - 40	PREP	Chamber pressure of prototype (PSI)
CARDS No 6	Prototype Fuel and Oxidizer Information	
FORMAT	5(A2, F7 0), 1X, A1, 1X, A1, 1X, 3E10 3	
Col 1 - 45	PNAME	Fuel or oxidizer name (Products must be on CEC products tape)
Col 47	LOF	F In col 48 denotes fuel
		O In col. 48 denotes oxidizer
Col 49	PHAZ	Phase of propellant L - Liquid
		G - Gas
Col 51 - 60	WTFRAC	Weight fraction of fuel or oxidizer
Col 61 - 70	HENTH	Heat of formation (in cal) of fuel or oxidizer

Col. 71 - 80	HTEMP	Temperature (^{o}K) associated with heat of formation
CARD NO 7	Region of Simulation	
FORMAT	7E10 6	
Col 1 - 10	XP11	Axial location of point nearest nozzle in region of plume to be simulated (X/D from nozzle)
Col 11 - 20	XP12	Axial location of central point in simulated region (X/D from nozzle)
Col 21 - 30	XP13	Axial location of rear point in simulated region (X/D from nozzle) (XP11, XP12, XP13)
Col 31 - 40	ERRMAX	Multiplication factor which may be input to modify the allowable percentage error used in the program. This allowable error is 10% and thus ERRMAX may be used to tighten or loosen this criteria (0< ERRMAX)

C 2.2 Description of Program Output

The simulant selection program output is organized into several basic groups which are easily recognizable The initial output consists of input data Thermodynamic data from the CEC portion of the program is then printed out The next area contains data from calculations for the Reynolds number Finally, a source flow plume is printed out. If this plume does not satisfy the required conditions a message is written out and further calculations are performed with output similar to that above Detailed explanations are listed below Numbered flags on the example output correspond to the numbered comments Only pertinent output pages are shown

Group I - Identification

(1) Title Identifies particular run.

Group II - Run Control

(2) Run Control Parameters These five parameters control program execution according to options selected (See input guide for explanation of individual parameters.)

Group III - Model Nozzle Information

(3) Model Nozzle Geometry These parameters are input and are explained in the input guide

(4) Chamber Conditions Chamber temperature and pressure are either input or set by program as determined by Group I parameters

Group IV - Prototype Nozzle Information

(5) Prototype Nozzle Geometry These parameters are input and are explained in the input guide

Group V - Plume Region Information

(6) Plume Region These parameters define a region of the plume to be duplicated They are explained in the input guide

(7) ERRMAX Described in input guide

Group VI - Prototype Gas Thermodynamic Information

This data is generated by the CEC portion of the program and contains data for an equilibrium combustion of the reactants and a frozen expansion of the products

(8) Gas Data This page contains the thermodynamic data for the prototype engine The tables are self-explanatory (Units are on output)

(9) This table contains gas parameters pertinent to the calculations of a source flow plume. This is the TAB array of the program

Group VIII - Prototype Reynolds Number Calculation

(10) Prototype Reynolds Number

Group IX - Prototype Plume

(11) Origin of source flow with respect to exit plane of nozzle - (ft)

(12) Expansion angle of flow at nozzle lip - (radians)

(13) Radial distance from source - (ft)

(14) Mach number - Local Mach number

(15) Reynolds number - Local Reynolds number

(16) Gamma - specific heat ratio

(17) Knudsen Number

(18) Stagnation temperature - (^{o}R)

(19) Static temperature - (^{o}R)

(20) Stagnation pressure - (psf)

(21) Static pressure - (psf)

(22) Condensation point of H_2O in prototype plume - (ft), ternary system only

Group X - Model Gas Mixture

(23) This data is computed by CEC portion of program. The tables are self-explanatory

(24) This table contains gas parameters used in the calculation of a source flow plume This is the TAB array

(25), (26) Gas data for individual species of gases in the simulant mixture Used in subsequent calculations (appear only when new gases or new chamber stagnation conditions are tried)

Group XI - Model Reynolds Number

This section contains exit plane properties and Reynolds number for model nozzle See Group VIII for explanation

Group XII Model Plume

Source flow plume for model nozzle See Group IX for explanation

C 3 SAMPLE IBM 7094 INSTRUCTION CARD

This sample card is included in the program direction to aid the user in running the program Naturally this format will vary from machine to machine The important data to note however, are the tape numbers and logic These contain the data necessary for the calculation of thermodynamic and transport properties of many gases See Refs 16 and 17

(1) Programmer name

(2) Operation code - 11-production

(3) Bin number - assigned by computer services

(4) Location - Return completed job to this area

(5) Job number - assigned by computer services

(6) Simulation gases products tape

(7) Transport property products tape

(8) Complete products tape for CEC (Used in prototype calculations)

(9) Time assigned by programmer (Usually 30 minutes of 7094 will suffice)

(10) Number of lines assigned by programmer (Usually 15,000 will suffice)

7094- _____ INSTRUCTIONS

NAME (1) | OP CODE (2) | STACK# ___

BIN# (3) | LOC (4) | JOB # (5)

IF EXCEEDS MAX (15)
☐STR ☐STP ☐DMP ☒RETSY

(12-13)

FAST TAPES A B C D

	INPUT TAPES			WORK LOGIC
	LOGIC	REEL NO	DEN	
(11) ☒IBSYS ☐SPOOK ☐OTHER ☒COMPL /ASSMBL ☒EXECUTE ☐PUNCH (BCD BIN)	(6) A5	2814		
	(7) A7	4640		
(14) ☒4 FTRN ☐2 FTRN ☐APT ☐PERT ☐MAP ☐FAP ☐SCAT ☐OTHER	(8) A8	4451		

LINES OF OUTPUT (1000S) (10)
☐0-5 ☐5-15 ☐15-30 ☐OVER

MAXIMUM TIME (9)
HOURS ____ MINUTES ____

PROGRAMMER COMMENTS

NUMBER OF CASES ____

OVER ____

OPERATOR COMMENTS

☐ SEE ON LINE
☐ SEE TECHNIQUE
☐ MAX EXCEEDED
☐ RETURN TO SYS
☐ LINE MAX

OPER INIT ____
OVER ____

OUTPUT TAPES ONLY — 4020

REEL NO	LOGIC	DEN	UNIT	NO OF CPYS	SAVE	TAPE
	B-1	8				

NO FILES	NO FRAMES	COPIES		DENSITY		COPY FLO		KALVAR
		P	F	5	8	P	F	
____	____							____

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(11) Job will be executed under IBM 7094 IBSYS system

(12) Computer is to compile and assemble the subroutines in binary form suitable for execution

(13) After compilation and loading of the binary form of the subroutines the program is to be executed

(14) The program coding is in FORTRAN IV language

(15) If either maximum time or maximum pages exceeded, the program control is to be returned to the IBSYS system and the job terminated

If the dump is checked and either of the above occurs, the computer operator will initiate a dump of the program and the variables stored in the core

Appendix D

PROGRAM LISTING AND PRINTOUT

```
$JOB            H029-LMSC L5207     ,911000,00,12,I40CEP
*       DATE    MAY 70     SEQ= G602
$EXECUTE        IBJOB
$IBJOB          MAP,LOGIC,GO,FIOCS,SOURCE,FLOW
$IBFTC MAIN
C       CONTROLLING PROGRAM
C       SETS INPUT ANDS CALLS CEC
C      TO LESSEN THE NO. OF CHANGES THAT MUST BE MADE, THE THERMODYNAMIC
C       DATA FOR THE TRANSPORT PROPERTIES WILL BE READ FROM TAPE 12, THE
C      OLD NASA/LEWIS DATA TAPE.
C       THE THERMODYNAMIC DATA FOR THE CEC PORTION WILL BE READ FROM TAPE
C       4, THE NEW DATA TAPE GENERATED BY MCDERMIT.
C       TO MAKE THESE COMPATABLE THE CEC IS MODIFIED TO READ THE GAS NAME
C       UNDER A 2A6 FORMAT.
       COMMON/PLUNMU/XC(5),PC(5),EMC(5),GMC(5),TC(5),QC(5),EMWC(5)
       COMMON/PLUMF1/PRPR(10,4),REYPLM
       COMMON/CHANGE/PC11,PC21,PC22,PC31,PC32,PC33,PNW,TNW,DEL,DELMN,
      $DELREY
       COMMON/PLUMF2/PROP(10,200),IPT
       COMMON/GASES/TAB(3,12,13),NMIX
       COMMON/GASFO/GASNAM(10,5,4),GNUM(10,5,4),NML(10,4),
      1FZG (10,4),FXG(10,4),ENTHG(10,4),RTEMPG(10,4)
       COMMON/SUNUP/SUN(3,40,2)
       COMMON/CHAMB/PCHAMI,TCHAMI,PMAX,TMAX
       COMMON/NUMG/IG1,IG2,IG3,IG4,PCMAX,IG
       INTEGER GASNAM
       COMMON/GEOM/AT,RADTHT,AEOAT,ANGLP,REYNP
       COMMON/LIP/THET,PI02
       COMMON/EXCON/PEX,EMU
       COMMON/MISC/ENN,SUMN,TT,SO,ATOM(3,101),LLMT(15),BO(15),BOP(15,2)
      1,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUBO,AC(2),AM(2)
      2,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)
      3,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15)
      4,RHOP,RMW(15),TLN
       COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)
      1,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13)
      2,TOTN(13)
       COMMON/COUNT/IKLUG
```

```
      COMMON/WRIT/IFLG1
      COMMON/TAPE/IPROT
      COMMON/MOLFRC/ZFRAC(40),KFR
       COMMON/PNT/KPT(4)
      DATA LANK/1H /
      COMMON/MGEOM/ATM,RADTHM,AEOATM,ANGLPM
      COMMON/MOLWT/SA,SB,SC
      DIMENSION PSI(10,4)
      LOGICAL KAZE
C     IRNK IS COUNTER IF MIXTURE CHANGES FOR REYNOLDS NO. CALC
      IRNK=0
      IKLUG=0
C     READ INPUT INFO AND SET GAS DATA
      CALL INPUT
      PCMAX=.5
      PI=3.14159
      P02=PI/2.0
C
      CALL PROTO
C     RESET GEOMETRY VALUES TO THOSE OF MODEL
      RADTHT=RADTHM
      AEOAT= AEOATM
      ANGLP= ANGLPM
      AT=ATM
C     USE CEMDAT TO SET UP POSSIBLE SIMULANT GAS NAMES
C     SET UP A STANDARD ARRAY TO CONTAIN POSSIBLE SIMULANT GAS DATA
C     LAST DIGIT DESIGNATES THE CATAGORY TO WHICH THE GAS BELONG
C     1 IS LOW-GAMMA GAS,2 IS HI-GAMMA GAS
C      3 IS CONDENSABLE
C     FIRST DICIT COUNTS NO. OF GASES IN CATAGORY
C     SECOND DIGIT INDICATES ELEMENT IN GAS TYPE
C     NEED TO LOAD IN REF. TEMP. AND ENTHALPY
      RTEMPG(1,2)=298.15
      ENTHG(1,2) =0.0
      RTEMPG(2,2)=298.15
      ENTHG(2,2) =0.0
      RTEMPG(3,2)=298.15
      ENTHG(3,2) =0.0
```

```
      RTEMPG(4,2)=298.15
      ENTHG(4,2) =19490.0
      RTEMPG(1,1)=298.15
      ENTHG(1,1) =-217200.0
      RTEMPG(2,1)= 298.15
      ENTHG(2,1) =-162600.0
      RTEMPG(1,3)=298.15
      ENTHG(1,3) =-94051.8
      RTEMPG(2,3)=298.15
      ENTHG(2,3) =-171900.0
      PSI(1,1)=88.
      PSI(2,1)=71.
      PSI(1,2)=28.
      PSI(2,2)=39.9
      PSI(3,2)=2.
      PSI(4,2)=44.
      PSI(1,3)=44.
      PSI(2,3)=106.4
C     INITIALIZE GUESS OF MIXTURE RATIO
      PC11=1.0
      PC21=0.5
      PC22=0.5
      PC31=0.4
      PC32=0.4
      PC33=0.2
      DP3=.05
      PHOLD=PCHAMI
      THOLD=TCHAMI
C     THIS SECTION INTIALIZES THE  GAS SELECTION PROCEDURE
C     L IS COUNTER ON CONDENSABLE
      L=1
C     KAZE IS SET FALSE IF MIXTURE IS CHANGED
      KAZE =.TRUE.
      KASE=0
      IRNT=0
       IF(IG.EQ.1)GO TO 400
      K=1
C     EVENTUALLY A SYSTEM WILL BE SET UP TO SELECT SINGLE GAS
```

```
C       THAT APPROXIMATES A PT IN THE FIELD
        IF(NMIX.EQ.3)GO TO 200
        IF(NMIX.GT.1)GO TO 100
   15   I=0
   20   I=I+1
   31   CONTINUE
        DO 11 J=1,5
        NAME(1,J)=GASNAM(I,J,K)
   11   ANUM(1,J)=GNUM(I,J,K)
        ENTH(1)=ENTHG(I,K)
        RTEMP(1)=RTEMPG(I,K)
        FAZ(1)=FZG(I,K)
        FOX(1)=FXG(I,K)
        PECWT(1)=PC11
        P=PHOLD
        T=THOLD
        NAME(2,1)=LANK
C
C       GO TO 400 ,CALL CEC FOR 1 GAS
        GO TO 400
  100   CONTINUE
        IT1=0
   21   IT1=IT1+1
   33   CONTINUE
        DO 12 J=1,5
        NAME(1,J)=GASNAM(IT1,J,1)
   12   ANUM(1,J)=GNUM(IT1,J,1)
        ENTH(1)=ENTHG(IT1,1)
        RTEMP(1)=RTEMPG(IT1,1)
        FAZ(1)=FZG(IT1,1)
        FOX(1)=FXG(IT1,1)
        SA = PSI(IT1,1)
        PECWT(1)=PC21
C
        IF(IRNK.EQ.1)GO TO 34
        IT2=0
   22   IT2=IT2+1
   34   CONTINUE
```

```
      DO 13 J=1,5
      SB = PSI(IT2,2)
      NAME(2,J)=GASNAM(IT2,J,2)
   13 ANUM(2,J)=GNUM(IT2,J,2)
      ENTH(2)=ENTHG(IT2,2)
      RTEMP(2)=RTEMPG(IT2,2)
      FAZ(2)=FZG(IT2,2)
      FOX(2)=FXG(IT2,2)
      PECWT(2)=PC22
      P=PHOLD
      T=THOLD
C
      NAME(3,1)=LANK
C     GO TO 400,CALL CEC FOR 2 GASES
      GO TO 400
  200 CONTINUE
C     INITIALIZE FOR TERNARY, USE CO2 FOR CONDENSABLE
      IT1=0
   23 IT1=IT1+1
   35 CONTINUE
      DO 14 J=1,5
      NAME(1,J)=GASNAM(IT1,J,1)
   14 ANUM(1,J)=GNUM(IT1,J,1)
      ENTH(1)=ENTHG(IT1,1)
      RTEMP(1)=RTEMPG(IT1,1)
      FAZ(1)=FZG(IT1,1)
      FOX(1)=FXG(IT1,1)
      SA = PSI(IT1,1)
      PECWT(1)=PC31
C
      IF(IRNK.EQ.1)GO TO 36
      IT2=0
   24 IT2=IT2+1
   36 CONTINUE
      DO 85 J=1,5
      NAME(2,J)=GASNAM(IT2,J,2)
   85 ANUM(2,J)=GNUM(IT2,J,2)
      ENTH(2)=ENTHG(IT2,2)
```

```
      RTEMP(2)=RTEMPG(IT2,2)
      FAZ(2)=FZG(IT2,2)
      FOX(2)=FXG(IT2,2)
      SB = PSI(IT2,2)
      PECWT(2)=PC32
C     SET CONDENSABLE CO2
      DO 16 J=1,5
      NAME(3,J)=GASNAM(L,J,3)
   16 ANUM(3,J)=GNUM(L,J,3)
      ENTH(3)=ENTHG(L,3)
      RTEMP(3)=RTEMPG(L,3)
      FAZ(3)=FZG(L,3)
      FOX(3)=FXG(L,3)
      SC = PSI(L,3)
      PECWT(3)=PC33
      P=PHOLD
      T=THOLD
      NAME(4,1)=LANK
  400 CONTINUE
      KASE=KASE+1
      WRITE(6,41)
   41 FORMAT(30X,31HGAS MIXTURE UNDER CONSIDERATION//35X,4HNAME,15X,
     113HMIXTURE RATIO)
      DO 42 MC=1,NMIX
      WRITE(6,44)(NAME(MC,IC),ANUM(MC,IC),IC=1,5),PECWT(MC)
   44 FORMAT(15X,5(A2,1X,F7.4,2X),5X,F7.4)
   42 CONTINUE
      CALL CEC(1,KASE)
      WRITE(6,310)
  310 FORMAT(1H1)
      WRITE(6,51)
   51 FORMAT(40X,45HTABLE OF THERMODYNAMIC PROPERTIES FOR MIXTURE)
      WRITE(6,52)
   52 FORMAT(15X,8HH FT2/S2,5X,4HA/A*,7X,5HGAMMA,6X,5HM NO.,10X,5HP PSF,
     16X,7HT DEG R,5X,6HMOL WT)
      NPT=KPT(1)
      WRITE(6,53)(( TAB(1,I,J),I=1,7),J=1,NPT)
   53 FORMAT(13X,E10.3,2X,E10.3,2X,E10.3,2X,E10.3,2X,E10.3,2X,E10.3,2X,
```

```
     $E10.3)
C      TEST IF MIXTURE GASES HAVE CHANGED
       IF(.NOT.IAZE)GO TO 801
C      NOW DETERMINE ENDPTS. OF MIXTURE
       IF(NMIX.EQ.1)GO TO 500
       IF(NMIX.EQ.2)GO TO 550
       IF(NMIX.EQ.3)GO TO 600
  500  IF(I.GE.IG1)GO TO 510
       GO TO 20
  510  IF(K.EQ.4)GO TO 1000
       K=K+1
       GO TO 15
  550  CONTINUE
       PECWT(1)=1.0
       NAME(2,1)=LANK
       P=PHOLD
       T=THOLD
       CALL CEC(2,KASE)
       DO 551 J=1,5
       NAME(1,J)=GASNAM(IT2,J,2)
  551  ANUM(1,J)=GNUM(IT2,J,2)
       RTEMP(1)=RTEMPG(IT2,2)
       ENTH(1)= ENTHG(IT2,2)
       FAZ(1) = FZG(IT2,2)
       FOX(1) = FXG(IT2,2)
       P=PHOLD
       T=THOLD
       CALL CEC(3,KASE)
C      AFTER CEC COMPUTES ENDPTS.,THE GAS NAMES MUST BE RESET
  580  DO 552 J=1,5
       NAME(1,J)=GASNAM(IT1,J,1)
  552  ANUM(1,J)=GNUM(IT1,J,1)
       ENTH(1) = ENTHG(IT1,1)
       RTEMP(1) =RTEMPG(IT1,1)
       FAZ(1)   =FZG(IT1,1)
       FOX(1)   =FXG(IT1,1)
       DO 553 J=1,5
       NAME(2,J)=GASNAM(IT2,J,2)
```

```
  553 ANUM(2,J)=GNUM(IT2,J,2)
      ENTH(2)  =ENTHG(IT2,2)
      RTEMP(2)  =RTEMPG(IT2,2)
      FAZ(2)   =FZG(IT2,2)
      FOX(2)   =FXG(IT2,2)
      PECWT(1)=PC21
      PECWT(2)=PC22
      NAME(3,1)=LANK
C     GAS PROPERTIES LOADED INTO TAB ARRAY,1-MIXTURE,2-ENDPT,3-ENDPT
      GO TO 800
  600 CONTINUE
C     NOW TO SET ENDPTS FOR TERNARY MIXTURE
      DO 554 J=1,5
      NAME(2,J)=GASNAM(L,J,3)
  554 ANUM(2,J)=GNUM(L,J,3)
      ENTH(2)  =ENTHG(L,3)
      RTEMP(2) =RTEMPG(L,3)
      FAZ(2)   =FZG(L,3)
      FOX(2)   =FXG(L,3)
      NAME(3,1)=LANK
      PECWT(1) =PC31+PC32
      PECWT(2) =PC33
      P=PHOLD
      T=THOLD
      CALL CEC(2,KASE)
      DO 555 J=1,5
      NAME(1,J)=GASNAM(IT2,J,2)
  555 ANUM(1,J)=GNUM(IT2,J,2)
      ENTH(1)  =ENTHG(IT2,2)
      RTEMP(1) =RTEMPG(IT2,2)
      FAZ(1)   =FZG(IT2,2)
      FOX(1)   =FXG(IT2,2)
      P=PHOLD
      T=THOLD
      CALL CEC(3,KASE)
C     AFTER TERNARY ENDPTS COMPUTED, RESET GASES
      PECWT(1)=PC31
      PECWT(2)=PC32
```

```
      DO 557 J=1,5
      NAME(1,J)=GASNAM(IT1,J,1)
  557 ANUM(1,J)=GNUM(IT1,J,1)
      ENTH(1)   =ENTHG(IT1,1)
      RTEMP(1)  =RTEMPG(IT1,1)
      FAZ(1)    =FZG(IT1,1)
      FOX(1)    =FXG(IT1,1)
      DO 558 J=1,5
      NAME(2,J)=GASNAM(IT2,J,2)
  558 ANUM(2,J)=GNUM(IT2,J,2)
      ENTH(2)  =ENTHG(IT2,2)
      RTEMP(2)  =RTEMPG(IT2,2)
      FAZ(2)    =FZG(IT2,2)
      FOX(2)    =FXG(IT2,2)
      DO 559 J=1,5
      NAME(3,J)=GASNAM(L,J,3)
  559 ANUM(3,J)=GNUM(L,J,3)
      ENTH(3)   =ENTHG(L,3)
      RTEMP(3)  =RTEMPG(L,3)
      FAZ(3)    =FZG(L,3)
      FOX(3)    =FXG(L,3)
      NAME(4,1)=LANK
C
  800 CONTINUE
      WRITE(6,310)
      WRITE(6,61)
   61 FORMAT(40X,49HTABLE OF THERMODYNAMIC PROPERTIES FOR COMPONENT 1)
      WRITE(6,52)
      NPT=KPT(2)
      WRITE(6,53)(( TAB(2,I,J),I=1,7),J=1,NPT)
      WRITE(6,310)
      WRITE(6,71)
   71 FORMAT(40X,49HTABLE OF THERMODYNAMIC PROPERTIES FOR COMPONENT 2)
      WRITE(6,52)
      NPT=KPT(3)
      WRITE(6,53)(( TAB(3,I,J),I=1,7),J=1,NPT)
  801 CONTINUE
C
```

```
C       COMPARE RN AT EXIT PLANE
        CALL COMPAR (1,IOK,IRCON,KASE)
        IRNK=0
        IF(IRNT.GE.1) GO TO 802
        IF(IRCON.EQ.1)GOTO1100
        IF(IOK.GT.1)GO TO 900
C       COMPUTE SOURCE FLOW PLUME
  802   CONTINUE
        IDZ=0
        CALL SOURCE(IDZ,ISCON)
        IF(ISCON.EQ.1)GO TO 1100
C       COMPARE PLUME  REGION
        CALL COMPAR(2,IOK,IDUM,KASE)
        IF(IG.EQ.1)GO TO 1100
        IF(IOK.EQ.0)GO TO 1000
        CALL ADJUST(      NOK,KAZE)
        IF(NMIX.EQ.1.AND.NOK.EQ.0)GO TO 855
        IF(NMIX.EQ.1.AND.NOK.GT.0)GO TO 850
        IF(NMIX.EQ.2.AND.NOK.EQ.0)GO TO 865
        IF(NMIX.EQ.2.AND.NOK.GT.0)GO TO 860
        IF(NMIX.EQ.3.AND.NOK.EQ.0)GO TO 875
        IF(NMIX.EQ.3.AND.NOK.GT.0)GO TO 870
C       MODIFY GASES ACCORDING TO INPUT FROM ADJUST
  850   THOLD=TNW
        PHOLD=PNW
        IRNK=0
        IF(I.LT.IG1)GO TO 20
        IF(I.GE.IG1)I=0
        K=2
        IF(I.GT.IG2)GO TO 1020
        GO TO 20
  855   T=TNW
        P=PNW
        THOLD=TNW
        PHOLD=PNW
        GO TO 400
  860   THOLD=TNW
        PHOLD=PNW
```

```
      IRNK=0
      PC21=.5
      PC22=.5
      IF(IT2.LT.IG2)GO TO 22
      IF(IT1.LT.IG1)GO TO 21
      GO TO 980
  865 T=TNW
      P=PNW
      PHOLD=PNW
      THOLD=TNW
      PECWT(1)=PC21
      PECWT(2)=PC22
      GO TO 400
  870 THOLD=TNW
      PHOLD=PNW
      IRNK=0
      PC31 =.4
      PC32=.4
      PC33=.2
      IF(IT2.LT.IG2)GO TO 24
      IF(IT1.LT.IG1)GO TO 23
      GO TO 985
  875 T=TNW
      P=PNW
      THOLD=TNW
      PHOLD=PNW
      PECWT(1)=PC31
      PECWT(2)=PC32
      PECWT(3)=PC33
      GO TO 400
  980 WRITE(6,981)
  981 FORMAT(5X,33HNO DESIRABLE BINARY MIXTURE FOUND)
      WRITE(6,706)
  706 FORMAT(20X,43HOTO ACHIEVE CONVERGENCE,INCREASE ERROR BAND)
      GO TO 1100
  985 WRITE(6,986)
  986 FORMAT(5X,72HNO DESIRABLE TERNARY MIXTURE FOUND FOR PRESENT CONDEN
     1SABLE RATIO, MODIFY)
```

```
      WRITE(6,706)
      PC33=PC33+DP3
      PH=(1.0-PC33)/2.0
      PC31=PH
      PC21=PH
      IF(PC33.LE.PCMAX)GO TO 200
      WRITE(6,701)
  701 FORMAT(5X,73HNO DESIRABLE TERNARY MIXTURE FOUND  FOR PRESENT CONDE
     2NSABLE, USE NEXT GAS)
      PC33=.2
      PC31=.4
      PC32=.4
      L=L+1
      IF(L.LE.IG3)GO TO 200
      WRITE(6,705)
  705 FORMAT(41HONO MIXTURES FOUND FOR PRESENT CONDITIONS)
      GO TO 1100
  900 CONTINUE
C     THIS SECTION  INCREASES CHAMBER TEMPERATURE TO COMPENSATE FOR
C     LOW REYNOLDS NO.
      T =TCHAMI + 300.
       WRITE(6,967)
  967 FORMAT(20X, 56HINCREASING CHAMBER TEMPERATURE TO RAISE  REYNOLDS N
     $UMBER)
      P= PCHAMI
      IRNT = IRNT+1
      PHOLD=P
      THOLD=T
      IRNK=1
      IF(NMIX.EQ.1)GO TO 31
      IF(NMIX.EQ.2)GO TO 33
      IF(NMIX.EQ.3)GO TO 35
 1000 CONTINUE
      IF(NMIX.EQ.2) GO TO 1100
      WRITE(6,1001)
 1001 FORMAT(73HOLAST COMPUTED MIXTURE ACCEPTABLE POINT OF CONDENSATION
     *NOW BEING CHECKED)
      ICON=L
```

```
      CALL CONDEN(ICON,ISW,IACP,TONEW)
      IF(ISW.EQ.0)GO TO 1010
      IF(IACP.EQ.0)GO TO 1050
C     TEMPERATURE CALCULATED IS UNACCEPTABLE, MODIFTY GASES
      NOK=1
      PNW=PCHAMI
      TNW=TCHAMI
      GO TO 870
 1050 NOK=0
      PNW=P
      TNW=TONEW
      GO TO 875
 1020 WRITE(6,1021)
 1021 FORMAT(31H0NO ACCEPTABLE SINGLE GAS FOUND)
 1010 CONTINUE
 1100 CONTINUE
      STOP
      END
```

```
$IBFTC INPUT1   DECK
      SUBROUTINE INPUT
      COMMON/MISC/ENN,SUMN,TT,SO,ATOM(3,101),LLMT(15),BO(15),BOP(15,2)
     1,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUBO,AC(2),AM(2)
     2,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)
     3,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15)
     4,RHOP,RMW(15),TLN
      COMMON/GASFO/GASNAM(10,5,4),GNUM(10,5,4),NML(10,4),
     1FZG (10,4),FXG(10,4),ENTHG(10,4),RTEMPG(10,4)
      COMMON/WRIT/IFLG1
      COMMON/GEOM/AT,RADTHT,AEOAT,ANGLP,REYNP
      COMMON/GASES/TAB(3,12,13),NMIX
      COMMON/CHAMB/PCHAMI,TCHAMI,PMAX,TMAX
      COMMON/NUMG/IG1,IG2,IG3,IG4,PCMAX,IG
      COMMON/PROTG/PNAME(4,5),AOF(4),WTFRAC(2),PNUM(4,5),HENTH(4),
     1HTEMP(4),PHAZ(4)
      COMMON/REGION/XPI1,XPI2,XPI3,ERRMAX,ITYPE
      COMMON/PROTN/RADP,AETP,ANGP,PREP
      COMMON/MGEOM/ATM,RADTHM,AEOATM,ANGLPM
      DIMENSION HEADER(12)
C     READ NO. OF GASES DESIRED IN MIXTURE AND NO. OF AXIAL PTS IN PLUME
      IG=0
      READ(5,1)(HEADER(I),I=1,12)
    1 FORMAT(12A6)
C     HEADER IDENTIFIES PARTICULAR RUN
      WRITE(6,100)
  100 FORMAT(1H1)
      WRITE(6,2)HEADER
    2 FORMAT(30X,12A6)
      READ(5,5)NMIX,NPTS,IP,IT,IG,IFLG1,ITYPE
    5 FORMAT(8I5)
      WRITE(6,7)NMIX,NPTS,IP,IT,IG,IFLG1,ITYPE
    7 FORMAT(15X,5HNMIX=,I5,5X,5HNPTS=,I5,5X, 3HIP=,I5,5X,3HIT=,I5,5X,
     13HIG=,I5,5X,6HIFLG1=,I5,5X,6HITYPE=I5)
      TMAX=2000.
      PMAX=1500.
      IF(IP.EQ.0.AND.IT.EQ.0)GO TO 20
      IF(IP.EQ.1.AND.IT.EQ.0)GO TO 10
```

```
      IF(IP.EQ.0.AND.IT.EQ.1)GO TO 15
C     READ BOTH INTIAL CHAMBER T AND P
      READ(5,6)PCHAMI,TCHAMI
    6 FORMAT(7E10.6)
      GO TO 30
   10 READ(5,6)PCHAMI
      GO TO 29
   15 READ(5,6)PDUM,TCHAMI
   20 PCHAMI=200.
   29 CONTINUE
      IF(IT.EQ.1)GO TO 30
      TCHAMI=1800.
   30 CONTINUE
C     READ GEOMETRY OF THROAT
      READ(5,6)ATM,RADTHM,AEOATM,ANGLPM
      WRITE(6,31)
   31 FORMAT(1H0////,40X,23HNOZZLE GEOMETRY FOLLOWS)
      WRITE(6,37)
   37 FORMAT(1H0,29X,11HTHROAT AREA,5X,13HTHROAT RADIUS,5X,10HAREA RATIO,
     $,5X,9HLIP ANGLE)
      WRITE(6,33)ATM,RADTHM,AEOATM,ANGLPM
   33 FORMAT(30X,6(E10.3,5X))
       TCHAMI=TCHAMI/1.8
      WRITE(6,91)TCHAMI,PCHAMI
   91 FORMAT(1H0//,30X,21HINITIAL CHAMBER TEMP=E10.3,5X,9HPRESSURE=E10.3
     1)
      READ(5,6)RADP,AETP,ANGP,PREP
      WRITE(6,110)
  110 FORMAT(1H0//,40X,21HPROTOTYPE INFORMATION)
      WRITE(6,120)RADP,AETP,ANGP,PREP
  120 FORMAT(30X,5HRADP=E10.3,5HAETP=E10.3,5HANGP=E10.3,5HPREP=E10.3)
      DO 140 I=1,2
      READ(5,130)(PNAME(I,J),PNUM(I,J),J=1,5),AOF(I),PHAZ(I),WTFRAC(I),
     $HENTH(I),HTEMP(I)
  140 CONTINUE
  130 FORMAT(5(A2,F7.0),1X,A1,1X,A1,1X,3E10.3)
C     ARE INITIAL GASES INPUT OR SELECTED BY PROGRAM
      IF(IG.EQ.0)GO TO 60
```

```
      L=0
      L=L+1
      DO 50 N=1,NMIX
      READ(5,40)(NAME(N,I),ANUM(N,I),I=1,5),PECWT(N),NML(N,L),ENTH(N),
     1FAZ(N),RTEMP(N),FOX(N),DENS(N)
   40 FORMAT(5(A2,F7.5),F7.5,A1,F9.5,A1,F8.5,A1,F8.5)
   50 CONTINUE
      WRITE(6 ,84)
   84 FORMAT( 40X,24HINPUT GAS FOR SINGLE RUN)
      DO 83 J=1,NMIX
      WRITE(6,81)(NAME(J,I),ANUM(N,I),I=1,5),PECWT(J),NML(J,L),ENTH(J),
     1FAZ(J),RTEMP(J),FOX(N),DENS(N)
   81 FORMAT(1X,5(A2,1X,F7.4,2X),F8.4,2X,A1,F11.2,2X,F8.3,2X,
     1A1,3X,F8.5)
   83 CONTINUE
   60 CONTINUE
      READ(5,6)XPI1,XPI2,XPI3,ERRMAX
C     XPI1 AN XPI3 ARE AXIAL PTS. DEFINING REGION OF INTEREST
      WRITE(6,150)
  150 FORMAT(1H0//,45X,32HREGION OF PLUME TO BE DUPLICATED)
      WRITE(6,160)XPI1,XPI2,XPI3
  160 FORMAT(35X,4HXP1=E10.3,2X,4HXP2=E10.3,2X,4HXP3=E10.3)
      WRITE(6,170)ERRMAX
  170 FORMAT(1H0///,30X,30HERROR MULTIPLICATION FACTOR = E10.3)
      RETURN
      END
```

```
$IBFTC TABL1    DECK
      SUBROUTINE TABLE (P,I1)
      COMMON/GASES/TAB(3,12,13),NMIX
      COMMON/PNT/KPT(4)
      COMMON/GASCON/GAMA,R,T0,P0,EM,RHO,T,WM ,Q
      COMMON/EI TH/H
C     IL IS THE NO. OF PRESSURE CUTS
      IL=KPT(I1)
      EQUIVALENCE(NPT ,IL)
      UGC=1545.
      I=I1
      RGC=UGC/TAB(I,7,IL)*32.174
      PP=P
      IF(PP.LT.TAB(I,5,IL))PP=TAB(I,5,IL)
      IF(PP.GT.TAB(I,5,1))PP=TAB(I,5,1)
      IF(P.LT.TAB(I,5,IL).OR.P.GT.TAB(I,5,1))GO TO 50
      IT=0
    5 IT=IT+1
      IF(PP.LE.TAB(I,5,IT))GO TO 5
      IT=IT-1
      HP=(PP-TAB(I,5,IT))/(TAB(I,5,IT+1)-TAB(I,5,IT))
      GAMA= TAB(1,3,IT)  +HP*(TAB(I,3,IT+1)-TAB(1,3,IT))
      XSIP=ALOG(TAB(I,5,IT)/TAB(I,5,IT+1))/ALOG(TAB(I,6,IT)/TAB(I,6,IT+1
     1))
      ONOX=1./XSIP
      T=(PP/TAB(I,5,IT))**ONOX*TAB(I,6,IT)
C     COMPUTE CP
      XSIH=(TAB(1,1,IT+1)-TAB(1,1,IT))/(TAB(1,6,IT+1)-TAB(1,6,IT))
      H=TAB(1,1,IT)+XSIH*(T-TAB(1,6,IT))
      H0=TAB(1,1,1)
      Q=SQRT(2.*ABS(H0-H))*(H0-H)/ABS(H0-H)
      QSQ=Q**2
      R=RGC
      A=SQRT(GAMA*R*T)
      EM=Q/A
      T0= T+ (GAMA-1.)*QSQ/(2.*GAMA*RGC)
      P0= PP*(T0/T)**(GAMA/(GAMA-1.))
      WM= TAB(I,7,IT)
```

```
      RHO= PP/(RGC*T) *32.174
      GO TO 100
   50 CONTINUE
C     COMPUTATION IF P OUTSIDE TABLE
      IF(P.GT.TAB(I,5,1))GO TO 70
       IF(P.LT.TAB(I,5,IL))GO TO 80
   70 T1=TAB(I,6,1)
      GAMA=TAB(I,3,1)
      H1=TAB(I,1,1)
      GO TO 90
   80 T1=TAB(I,6,IL)
      GAMA=TAB(I,3,IL)
      H1=TAB(I,1,IL)
   90 CONTINUE
      T=T1*(P/PP)**((GAMA-1.)/GAMA)
      A=SQRT(GAMA*RGC*T)
C     TAB(I,1,IP) WILL CONTAIN ENTHALPY
C     XSIH IS CP
      XSIH=GAMA*RGC/(GAMA-1.)
      H=H1+XSIH*(T-T1)
      H0=TAB(I,1,1)
      Q=SQRT(2.*(H0-H))
      RHO= P/(T*RGC)*32.174
      EM = Q/A
      WM=TAB(I,7,1)
      R=RGC
      T0=T+(GAMA-1.)/(2.*GAMA*R)*Q**2
      P0=P*(T0/T)**(GAMA/(GAMA-1.))
  100 RETURN
      END
```

```
$IBFTC CEMDAT  DECK
       BLOCK DATA
       COMMON/GASFO/GASNAM(10,5,4),GNUM(10,5,4),NML(10,4),
      1FZG(10,4),FXG(10,4),ENTHG(10,4),RTEMPG(10,4)
       COMMON/NUMG/IG1,IG2,IG3,IG4,PCMAX,IG
       DATA IG1/3/,IG2/4/,IG3/1/,IG4/1/
       DATA(GASNAM(1,I,1),I=1,5)/2HS ,2HF ,2H  ,2H  ,2H  /
       DATA(GNUM(1,I,1),I=1,5)/1.0,6.0,0.0,0.0,0.0,0.0/
       DATA NML(1,1)/1HM/,FZG(1,1)/1HG/,FXG(1,1)/1HF/
       DATA(GASNAM(2,I,1),I=1,5)/2HC ,2HF ,2H  ,2H  ,2H  /
       DATA (GNUM(2,I,1),I=1,5)/1.0, 4.0,0.0, 0 ,0, 0.0/
       DATA  NML(2,1)/1HM/,FZG(2,1)/1HG/,FXG(2,1)/1HF/
       DATA(GASNAM(3,I,1),I=1,5)/2HC ,2HH ,2HF ,2H  ,2H  /
       DATA (GNUM(3,I,1),I=1,5)/1.0, 1.0, 3.0,0.0,0.0,0.0/
       DATA  NML(3,1)/1HM/,FZG(3,1)/1HG/,FXG(3,1)/1HF/
       DATA (GASNAM(1,I,2),I=1,5)/2HN ,2H  ,2H  ,2H  ,2H  /
       DATA (GNUM(1,I,2),I=1,5)/2.0,0.0,0.0,0.0,0.0,0.0/
       DATA  NML(1,2)/1HM/,FZG(1,2)/1HG/,FXG(1,2)/1HF/
       DATA (GASNAM(2,I,2),I=1,5)/2HAR,2H  ,2H  ,2H  ,2H  /
       DATA (GNUM(2,I,2),I=1,5)/1.0,0.0,0.0,0.0,0.0,0.0/
       DATA  NML(2,2)/1HM/,FZG(2,2)/1HG/,FXG(2,2)/1HF/
       DATA (GASNAM(3,I,2),I=1,5)/2HH ,2H  ,2H  ,2H  ,2H  /
       DATA (GNUM(3,I,2),I=1,5)/2.0,0.0,0.0,0.0,0.0,0.0/
       DATA  NML(3,2)/1HM/,FZG(3,2)/1HG/,FXG(3,2)/1HF/
       DATA (GASNAM(4,I,2),I=1,5)/2HN ,2HO ,2H  ,2H  ,2H  /
       DATA (GNUM(4,I,2),I=1,5)/2.0, 1.0,0.0,0.0,0.0,0.0/
       DATA  NML(4,2)/1HM/,FZG(4,2)/1HG/,FXG(4,2)/1HF/
       DATA (GASNAM(1,I,3),I=1,5)/2HC ,2HO ,2H  ,2H  ,2H  /
       DATA (GNUM(1,I,3),I=1,5)/1.0, 2.0, 0.0, 0.0, 0.0/
       DATA  NML(1,3)/1HM/,FZG(1,3)/1HG/,FXG(1,3)/1HF/
       DATA (GASNAM(2,I,3),I=1,5)/2HC ,2HCL, 2HF ,2H  ,2H  /
       DATA (GNUM(2,I,3),I=1,5)/1.0, 1.0, 3.0,0.0,0.0,0.0/
       DATA  NML(2,3)/1HM/,FZG(2,3)/1HG/,FXG(2,3)/1HF/
       END
```

```
$IBFTC ITSUB1  DECK
      SUBROUTINE ITSUB (FOFY,Y,SAVE,CONV,NTIMES)
C     REVISED MARCH 5, 1969
C     THIS SUBROUTINE PROVIDES ITERATION CONTROL FOR ANY FUNCTION          0010
C     OF ONE VARIABLE                                                      *20
C     (FOFX)-FUNCTION WHICH IS DRIVEN TO ZERO                              0030
C     (X)-VARIABLE WHICH IS ITERATIVELY SOLVED FOR                         0040
C     (SAVE)-PROGRAM CONTROL                                               050
C       SAVE(1)=ITIME                                                      060
C        SAVE(2)=X INCREMENT                                               0070
C        SAVE(3)=COUNTER DENOTING NTH ITERATION                            0080
C        SAVE(4-7)=STORAGE LOCATIONS FOR X AND FOFX                        0090
C        SAVE( 9-12) = STORAGE LOCATIONS FOR SUCCESSIVE  X  VALUES
C        SAVE(13-14) = STORAGE LOCATIONS FOR  MX  AND  NXX
C        SAVE(15) = ITERATION TIME SUBTOTAL
C        SAVE(16) = FOFY
C     (CONV)-CONVERGENCE CRITERIA                                          0100
C     (NTIMES)-MAX NUMBER OF ITERATIONS                                    0110
      DIMENSION SAVE(16)
      MX  = SAVE(13)
      NXX = SAVE(14)
      N1=SAVE(3) +.1                                                       0140
      N2=SAVE(15)+1.0
      SAVE(16) = FOFY
      IF(N2.NE.1) GO TO 5
      NXX=0
      MX = 8
    5 CONTINUE
      NX=N2/4 - NXX
      FOFXCK=SAVE(8)                                                       0150
C     FOFY AND Y ARE DUMMY  INPUT ARGUMENTS                                0160
      FOFX=FOFY                                                            0170
      X=Y                                                                  0180
C     CHECK FOR CONVERGENCE                                                0190
      IF(ABS (FOFX)-CONV.LE.0.)GOTO110                                     0200
      ITIME=SAVE(1)+.1                                                     0210
C     ITIME CONTROLS THE TYPE CALCULATION TO BE PERFORMED                  0220
C        ITIME=1,FIRST TIME THROUGH                                        0230
```

```
C       ITIME=2,POS FIRST TIME THROUGH                                  0240
C         ITIME=3,NEG FIRST TIME THROUGH                                0250
C         ITIME=4,SOLUTION IS BRACKETED                                 0260
C         ITIME=5,SOLUTION HAS CONVERGED                                0270
C         ITIME=6,SOLUTION WILL NOT CONVERGE                            0280
C       AJUMP=0.0
        GOTO(10,30,50,70),ITIME                                         0290
C       INITIALIZE                                                      0300
   10   N1=1                                                            0310
        ITIME=2                                                         0320
        FOFXCK=FOFX                                                     0330
        SAVE(8)=FOFXCK                                                  0340
        IF(FOFX.LT.0.)GOTO50                                            0350
   30   IF(FOFX.LT.0.)GOTO70                                            0360
        IF(FOFXCK.GE.FOFX)GOTO35                                        0370
        SAVE(2)=-1.*SAVE(2)                                             0380
        X=X-2.*SAVE(2)                                                  0390
        GOTO90                                                          0400
   35   IF(N1.EQ.1) GO TO 40
C       ACHECK=(SAVE(5)-FOFX)/SAVE(5)
C       IF(ACHECK.LT.0.3) AJUMP=+1.0
C       IF(ACHECK.LT.0.2) AJUMP=+2.0
   40   SAVE(4)=X
        SAVE(5)=FOFX                                                    0420
        X=X-SAVE(2)                                                     0430
        GOTO90                                                          0440
   50   ITIME=3                                                         0450
        IF(FOFX.GT.0.)GOTO70                                            0460
        IF(FOFXCK.LE.FOFX)GOTO55                                        0470
        SAVE(2)=-1.*SAVE(2)                                             0480
        X=X+2.*SAVE(2)                                                  0490
        GOTO90                                                          0500
   55   IF(N1.EQ.1) GO TO 60
C
C       IF(ACHECK.LT.0.3) AJUMP=-1.0
C       IF(ACHECK.LT.0.2) AJUMP=-2.0
   60   SAVE(6)=X
        SAVE(7)=FOFX                                                    0520
```

```
      X=X+SAVE(2)                                                          0530
      GOTO90                                                               0540
   70 ITIME=4                                                              0550
      N1=SAVE(3)                                                           0560
      N2=0
      IF(FOFX.LT.0.)GOTO75                                                 0570
      SAVE(4)=X                                                            0580
      SAVE(5)=FOFX                                                         0590
      GOTO80                                                               0600
   75 SAVE(6)=X                                                            0610
      SAVE(7)=FOFX                                                         0620
C       PICK NEW GUESS FOR X ACCORDING TO TYPE CALCULATION                 0630
   80 X=SAVE(4)-SAVE(5)*((SAVE(6)-SAVE(4))/(SAVE(7)-SAVE(5)))              0640
   90 IF(N1.GE.NTIMES)GOTO100                                              0650
C     X=X-AJUMP*SAVE(2)
      MX=MX+1
      SAVE(MX) = X
      IF(NX.EQ.0) GO TO 92
      MX = 8
      NXX=NXX+1
   92 CONTINUE
C     TEN ITERATION WILL BE ALLOWED BEFORE MAKING THE TEST OF  X  VALUE
      IF(N1.LT.10) GO TO 95
      IF((SAVE(12)-SAVE(10)).NE.0..OR.(SAVE(11)-SAVE(9)).NE.0.) GO TO 95
C     X VALUE HAS BEEN REPEATING, SET ITIME=4 -- SO THAT THE VALUE OF
C          SAVE(2) CAN BE ADJUSTED IN THE CALLING ROUTINE
      ITIME=4
      N2=0
   95 CONTINUE
      N1=N1+1                                                             *660
      SAVE(3)=N1                                                           0670
      GOTO120                                                              0680
  100 ITIME=6                                                              0690
      GOTO120                                                              0700
  110 ITIME=5                                                              0710
      SAVE(4)=X                                                            0720
      SAVE(5)=FOFX                                                         0730
      SAVE(6)=X                                                            0740
```

```
      SAVE(7)=FOFX                                                    0750
  120 SAVE(1)=FLOAT(ITIME)+.1                                         0760
      SAVE(13) = MX
      SAVE(14) = NXX
      SAVE(15)=N2
      Y=X                                                             0770
      RETURN                                                          0780
      END                                                             0790
```

```
$IBFTC PROTO1  DECK
      SUBROUTINE PROTO
C     PRODUCES PROTOTYPE PLUME
      COMMON/GASES/TAB(3,12,13),NMIX
      COMMON/REGION/XC11,XC12,XC13,ERRMAX,ITYPE
      COMMON/PLUMF1/PRPR(10,4),REYPLM
      COMMON/PLUMF2/PROP(10,200),IPT
      COMMON/GEOM/AT,RADTHT,AEOAT,ANGLP,REYNP
      COMMON/PNT/KPT(4)
      COMMON/EXCON/PEX,EMU
      DIMENSION H2O(10)
      COMMON/MOLFRC/ZFRAC(40),KFR
      COMMON /PROSAT/XSAT
      INTEGER PNAME
      COMMON/PROTG/PNAME(4,5),AOF(4),WTFRAC(2),PNUM(4,5),HENTH(4),
     1HTEMP(4),PHAZ(4)
      COMMON/SUNUP/SUN(3,40,2)
      COMMON/PROTN/RADP,AETP,ANGP,PREP
      COMMON/TAPE/IPROT
      DATA LLK/1H /
      COMMON/MISC/ENN,SUMN,TT,SO,ATOM(3,101),LLMT(15),BO(15),BOP(15,2)        160
     1  ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUBO,AC(2),AM(2)     170
     2  ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)              180
     3  ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15)     190
     4  ,RHOP,RMW(15),TLN
      COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)
     1,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13)
     2,TOTN(13)
      DATA(H2O(I),I=1,7)/-.111333E+03,-.816633E+02,+.273088E+02,+.110650E
     $E+01,-.560044E+00,-.191904E-01,+.546921E-02/
      DATAWATER,CARBO2/6HH2O    ,6HCO2    /
      DIMENSION CO2(10),ARG(10),CON(10)
       DATA(CO2(I),I=1,4)/-0.11763432E+03,-0.15185070E+02,+0.15828812E+0
     $2,-0.16524522E+01/
C     LOAD GASES INTO CEC ARRAY
      DO 20 I=1,5
      NAME(1,I)=PNAME(1,I)
   20 ANUM(1,I)=PNUM(1,I)
```

```
      PECWT(1)=WTFRAC(1)
      ENTH(1)=HENTH(1)
      RTEMP(1)=HTEMP(1)
      FOX(1)=AOF(1)
      FAZ(1)=PHAZ(1)
      DO 30 I=1,5
      NAME(2,I)=PNAME(2,I)
   30 ANUM(2,I)=PNUM(2,I)
      PECWT(2)=WTFRAC(2)
      ENTH(2)=HENTH(2)
      RTEMP(2)=HTEMP(2)
      FOX(2)=AOF(2)
      FAZ(2)=PHAZ(2)
      NAME(3,1)=LLK
      P=PREP
C     IPROT CONTROL WHICH PRODUCTS TAPE WILL BE READ IN CEC
      IPROT=1
      CALL CEC(1,KASE)
      WRITE(6,52)
   52 FORMAT(15X,8HH FT2/S2,5X,4HA/A*,7X,5HGAMMA,6X,5HM NO.,10X,5HP PSF,
     16X,7HT DEG R,5X,6HMOL WT)
      NPT=KPT(1)
      WRITE(6,53)(( TAB(1,I,J),I=1,7),J=1,NPT)
   53 FORMAT(13X,E10.3,2X,E10.3,2X,E10.3,2X,E10.3,2X,E10.3,2X,E10.3,
     $2X,E10.3)
C     COMPUTE REYNOLDS NO.
      RADTHT=RADP
      AEOAT=AETP
      ANGLP=ANGP
      AT = 3.174*RADP**2
      DEP = 2.*RADTHT*SQRT(AEOAT)
      CALL REYN(1,REY,IRCON)
      WRITE(6,4242) REY
 4242 FORMAT(1H0,20X,37HPROTOTYPE EXIT PLANE REYNOLDS NO. IS E10.3)
C     PRODUCE SOURCE FLOW PLUME
      CALL SOURCE(IDUM,ISCON)
C     RESET PROTOTYPE PLUME POINTS TO THOSE AXIAL POSITIONS INPUT
      CALL RESET
```

```
C       COMPUTE APPROXIMATE REYNOLDS NUMBER FOR PROTOTYPE
        IF(ITYPE.EQ.3) CALL REYN(2,REYPL,IRCON)
        IPROT=0
C       RE-INITIALIZE TAB ARRAY TO ZERO
        DO 40 I=1,13
        DO 40 J=1,12
   40   TAB(1,J,I)=0.
        REYNP=REY
        REYPLM=REYPL
C       TMAX=647.0
        TMAX = ALOG(300.)
        WRITE(6,778)KFR
        WRITE(6,779)(ZFRAC(IZ),IZ=1,KFR)
  778   FORMAT(17H0ZFRAC ARRAY,KFR=I5)
  779   FORMAT(5X,8E10.3)
C       SEARCH SUN ARRAY FOR C02
        IH=0
        DO 10 I=1,10
   10   CON(I)=C02(I)
   50   IH=IH+1
        WRITE(6,777)SUN(1,IH,1)
  777   FORMAT(10X,10HSUN ARRAY ,A6)
        IF(SUN(1,IH,1).EQ. WATER) GO TO 60
        IF(SUN(1,IH,1).EQ.CARB02) GO TO 60
        IF(IH.EQ.KFR)GO TO 55
        GO TO 50
   55   XSAT=1000.
        GO TO 150
   60   HMOL=ZFRAC(IH)
        WRITE(6,1881) HMOL
 1881   FORMAT(17H0HMOLE IN PROTO =E10.3)
        IF(HMOL.LE.1.E-06) GO TO 55
C       SEARCH PLUME FOR SAT. POINT
        IT=0
   70   IT=IT+1
C       CHANGE P AND T TO LOG VALUES BECAUSE VAPOR PRES. CURVE FIT
C       IS FOR LOG COOR.
        PL = ALOG(PROP(5,IT)/(14.7*144.)*HMOL)
```

```
      TL= ALOG(PROP(6,IT)/1.8)
      IF(TL.GE.TMAX) GO TO 70
C     PVAP= H2O(1)+H2O(2)*TL +H2O(3)*TL**2+ H2O(4)*TL**3+H2O(5)*TL**4
C    A+H2O(6)*TL**5+ H2O(7)*TL**6
      PVAP = CON(1)+CON(2)*TL+CON(3)*TL**2 +CON(4)*TL**3
      IF(PL.LE.PVAP) GO TO 80
C     FOR BRACKETED POINT
      DT=TH-TL
      DP1=PLH-PL
      DP2= PVAPH-PVAP
      SLP1=DP1/DT
       SLP2=DP2/DT
      GO TO 90
   80 CONTINUE
      IF(IT.EQ.1) GO TO 120
      PLH=PL
      PVAPH=PVAP
      TH=TL
      GO TO 70
   90 CONTINUE
      TINSCT = EXP((PVAP-PL + TL*(SLP1-SLP2))/(SLP1-SLP2))
      TLI = ALOG(TINSCT)
      PINSCT = EXP(SLP1*(TLI-TL)+PL)
      PTINS = PINSCT/HMOL
C     COMPUTE AXIAL LOCATION OF CONDENSATION
      SLPX = ALOG(PROP(5,IT)/PROP(5,IT-1))/ALOG(PROP(1,IT)/PROP(1,IT-1))
      ONOS= 1./SLPX
      XINSCT= PROP(1,IT-1)*EXP(ONOS*ALOG(PTINS/PROP(5,IT-1)))
      WRITE(6,100) XINSCT
  100 FORMAT(10X,38HPROTOTYPE CONDENSATION OCCURS AT ,E10.3)
      GO TO 130
  120 WRITE(6,121)
  121 FORMAT(10X,56HSATURATION OCCURS IN OR NEAR NOZZLE, XINSCT SET TO
     *ZERO)
      XINSCT=0.
  130 XSAT = XINSCT
  150 CONTINUE
      RETURN
      END
```

```
$*
$ORIGIN         B
$IBFTC COMP
       SUBROUTINE COMPAR(ITYP,ICK,IRCON,KASE)
       COMMON/PLUNMU/XC(5),PC(5),EMC(5),GMC(5),TC(5),QC(5),EMWC(5)
       COMMON/GASES/TAB(3,12,13),NMIX
       COMMON/SUNUP/SUN(3,40,2)
       COMMON/WRIT/IFLG1
       COMMON/TAPE/IPROT
       COMMON/NUMG/IG1,IG2,IG3,IG4,PCMAX,IG
       COMMON/CHANGE/PC11,PC21,PC22,PC31,PC32,PC33,PNW,TNW,DELM,DELMN,
      $DELREY
       COMMON/GEOM/AT,RADTHT,AEOAT,ANGLP,REYNP
       COMMON/REGION/XC11,XC12,XC13,ERRMAX,ITYPE
       COMMON/PLUMF1/PRPR(10,4),REYPLM
       DIMENSION EP(50),EPS(5)
       ICK=0
       KACE = KASE
       IF(ITYP.GT.1)GO TO 100
       CALL REYN(1,REY,IRCON)
       WRITE(6,5)REY
     5 FORMAT(20X,21HSIMULANT RN AT EXIT =,E10.3)
       IF(REY.LT.REYNP)ICK=2
       GO TO 300
   100 CONTINUE
       CALL RESET
       GO TO (120,130,140),ITYPE
   120 CONTINUE
C      COMPARE PLUME REGION FOR MOMENTUM FLUX
       EPSUM=0
       DO 50 J=1,3
       G1=GMC(J)
       P1=PC(J)
       EM1=EMC(J)
       G2=PRPR(3,J)
       P2=PRPR(5,J)
       EM2=PRPR(4,J)
C      COMPUTE ERROR
```

```
      EPS(J)=FMOM(G1,P1,FM1)-FMOM(G2,P2,EM2)
      EPSUM=EPSUM+EPS(J)
   50 CONTINUE
      EP(KACE)=EPSUM
      WRITE(6,60)EPSUM,KACE
   60 FORMAT(20X,23HSUMMATION OF MOM ERROR=,E10.3,2X,10HFOR CASE  ,I5)
C
C     ALSO COMPARE CENTER PT.
      DELM=EPS(2)
      PCM=DELM/FMOM(PRPR(3,2),PRPR(5,2),PRPR(4,2))
      WRITE(6,70)DELM,PCM
   70 FORMAT(1H2,5HDELM=,E10.3,5X,4HPCM=,E10.3)
      IF(ABS(PCM).GT..1*ERRMAX)ICK=3
      GO TO 300
  130 CONTINUE
C     COMPARE PLUME REGION FOR MACH NO.
      DELMN=EMC(4)-PRPR(4,2)
      PCMN = DELMN/PRPR(4,2)
       WRITE(6,132) DELMN,PCMN
  132 FORMAT(20X,17HOMACH NO. ERROR= E10.3,2X,18HPERCENTAGE ERROR= E10.3)
     $)
      IF(ABS(PCMN).GT..1*ERRMAX) ICK=3
      GO TO 300
  140 CONTINUE
C     COMPARE PLUME REGION FOR REYNOLDS NJMBER
      CALL REYN(2,REYM,IRCON)
      DELREY=REYPLM-REYM
      PCREY= DELREY/REYNP
      WRITE(6,142) DELREY,PCREY
  142 FORMAT(20X, 21HOREYNOLDS NO. ERROR= E10.3,2X,18HPEPCENTAGE ERROR =,
     1E10.3)
      IF(ABS(PCREY).GT..1*ERRMAX) ICK=3
  300 CONTINUE
      RETURN
      END
```

```
$IBFTC FMOM1    DECK
       FUNCTION FMOM(G,P,EM)
       FMOM=G*P*EM**2
       RETURN
       END
```

```
$IBFTC REYN1
      SUBROUTINE REYN(LTYPE,REY,IRCON)
C     SUBROUTINE REYN COMPUTES REYN. NO. AT EXIT PLANE
C     USING PROPERTIES FROM THE TAB ARRAY
C
      COMMON/GASES/TAB(3,12,13),NMIX
      COMMON/SUNUP/SUN(3,40,2)
      COMMON/SPNAME/SPNAM1(90),SPNAM2(90),TEMP( 5, 90),IDATA,KK,KT
      COMMON/NUMG/IG1,IG2,IG3,IG4,PCMAX,IG
      COMMON/GASCON/GAMA,R,T0,P0,EM,RHO,T,WM ,Q
      COMMON/GEOM/AT,RADTHT,AEOAT,ANGLP,REYNP
      COMMON/EXCON/PEX,EMU
      COMMON/PLUMF1/PRPR(10,4),REYPLM
      COMMON/TAPE/IPROT
      COMMON/PLUNMU/XC(5),PC(5),EMC(5),GMC(5),TC(5),QC(5),EMWC(5)
      COMMON/MOLFRC/ZFRAC(40),KFR
      COMMON/WRIT/IFLG1
      COMMON/COUNT/IKLUG
      DIMENSION SAVEA(16)
      DATA (SAVEA(K),K=1,16) /16*0./
      EQUIVALENCE (GAMMA,GAMA)
      IRCON=0
C     REYN COMPUTS REYNOLDS NO. AT AT  PT. KNOWING THE THERMO
C     PROPERTIES..... EXIT CONDITIONS ARE GENERALLY CALLED
C     FIRST GUESS FOR EXIT PRESSURE
      P=.005*TAB(1,5,1)
      SSQR=AEOAT
      TOL=0.005*SSQR
      SAVEA(1)=1.0
       PINC=-.09*P
      SAVEA(2)=PINC
      PSTAR=TAB(1,5,2)
      CALL TABLE(PSTAR,1)
      RSTAR=RHO
      QSTAR=Q
C     BYPASS EXIT PLANE CALC IF PLUME RN IS DESIRED
      IF(LTYPE.EQ.2)GO TO 200
   18 CONTINUE
```

```
      IF(P.GT.0.)GO TO 30
      P=P-.95*PINC
      PINC=.1*PINC
      SAVEA(2)=PINC
   30 CONTINUE
      CALL TABLE(P,1)
      ARAT=RSTAR*QSTAR/(RHO*Q)
      FP= SSQR-ARAT
      GO TO 198
        WRITE(6,39)
   39 FORMAT(20HOTABLE CHECK--GASCON)
      WRITE(6,40)GAMA,R,T0,P0,EM,RHO,T,WM,Q
   40 FORMAT(10X,9E10.3)
      WRITE(6,4000)RHO,Q,GAMA,GAMMA
 4000 FORMAT(1H0,4HRHO=E10.3,2HQ=E10.3,5HGAMA=E10.3,6HGAMMA=E10.3)
      WRITE(6,100)SSQR,ARAT,FP,P,SAVEA(2)
  100 FORMAT(6HOSSQR=,E10.3,5HARAT=,E10.3,3HFP=,E10.3,5HPRES=,E10.3,
     15HPINC=,E10.3)
  198 CONTINUE
      CALL ITSUB(FP,P,SAVEA,TOL,199)
      II=SAVEA(1)+.1
      N1=SAVEA(3)+.1
      GO TO (18,18,18,18,22,23),II
   23 WRITE(6,600)FP,P
  600 FORMAT(36H0ITSUB WILL NOT CONVERGE IN REYN,FP=,E10.3,5X,2HP=,E10.3
     1)
      IRCON=1
      RETURN
   22 CONTINUE
      PEX = P
      GO TO 300
  200 CONTINUE
C     LOAD PLUME PROPERTIES INTO P AND T
      IF(IPROT.EQ.1) GO TO 210
      P=PC(2)
      T=TC(2)
      GO TO 300
  210 P=PRPR(5,2)
```

```
      T=PRPR(6,2)
  300 CONTINUE
      GO TO 400
      IF(IPROT.EQ.1) GO TO 400
      TR=T
C     THE FIRST DIGIT IN TAB AND SUN INDICATES IF GAS IS MIXTURE
C     OR COMPONENT
C     3RD DIGIT OF SUN INDICATES PART OF GAS NAME
C     FIRST LOAD THE NAME INTO TEMP
      K=NMIX+8
      DO 5  KM=1,NMIX
      TEMP(1,KM+7)=SUN(  1,KM,1)
    5 TEMP(2,KM+7)=SUN(1,KM,2)
C     LOAD MOLE FRACTION INTO TEMP
C     IF PROTOTYPE CALC., USE MOLE FRAC. FROM ZFRAC
      IF(IPROT.EQ.1)GO TO 70
      DO 10 KM=9,K
   10 TEMP(3,KM-1)=TAB(1  ,KM,1)
      GO TO 80
   70 CONTINUE
      DO 75 KL=1,KFR
   75 TEMP(3,KL+7)=ZFRAC(KL)
   80 CONTINUE
      IWRIT=1
      WRITE(6,16)
   16 FORMAT(51HORE WRITING GAS NAME AND MOLE FRACTION USED IN REYN)
      DO 17 N=1,NMIX
   17 WRITE(6,28)   TEMP(1,N+7),TEMP(2,N+7),TEMP(3,N+7)
   28 FORMAT(1H0,5X,2A6,E10.3)
   15 CONTINUE
      CALL TRANS(TR,1,EMU)
C     COMPUTATION OF REYNOLDS NO.
      REX =RADTHT*SQRT(AEOAT)
      EMU=EMU*.0671983
      REY= RHO*Q*2.0*REX/EMU
      GO TO 500
  400 ROUSTR=RSTAR*QSTAR
      VIS = .1335E-4*(T/1.8)**.95
       EL= RADTHT*SQRT(AEOAT)
      REY=ROUSTR*2.*EL/VIS
  500 CONTINUE
      RETURN
      END
```

```
$ORIGIN        C
$IBFTC CONDNS
      SUBROUTINE CONDEN(ICON,ISWTCH,IACP,TONEW)
      COMMON/GASES/TAB(3,12,13),NMIX
C     COEFFICIENTS FOR VAPOR PRESSURE CURVES ARE COMPUTED FOR LOG
      COMMON/PLUMF2/PROP(10,200),IPT
      COMMON/PROSAT/XSAT
      COMMON/SUNUP/SUN(3,40,2)
      COMMON/MOLFRC/ZFRAC(40),KFR
      COMMON/REGION/XC11,XC12,XC13,ERRMAX,ITYPE
      COMMON/MGEOM/ATM,RADTHM,AEOATM,ANGLPM
      DATA CARB02/6HC02    /
C     COMPARE PROPERTY  ALONG EXPANSION--PROP--WITH VAPOR PRESSURE
C     CURVE
C     TYPE FIT. THUS THE CONVERSION OF THE PLUME DATA.
C
      DIMENSION CO2(10),ARG(10),CON(10)
       DATA(CO2(I),I=1,4)/-0.11763432E+03,-0.15185070E+02,+0.15828812E+0
     $2,-0.16524522E+01/
C     TEST GAS TYPE
      IF(ICON.EQ.2)GO TO 20
      DO 10 I=1,10
   10 CON(I)=CO2(I)
      TMAX=ALOG(300.)
      GO TO 40
   20 DO 30 I=1,10
   30 CON(I)=ARG(I)
      TMAX=ALOG(300.)
   40 CONTINUE
      IH =0
  150 IH=IH+1
      WRITE(6,777)SUN(1,IH,1)
  777 FORMAT(10X,10HSUN ARRAY ,A6)
      IF(SUN(1,IH,1).EQ.CARB02) GO TO160
      GO TO150
  160 XCON=ZFRAC(IH)
      WRITE(6,500)XCON
  500 FORMAT(20X,5HXCON=E10.3)
```

```
      I=0
   50 I=I+1
      P1= ALOG (PROP(5,I)*XCON/(14.7*144.))
      T1=ALOG  (PROP(6,I)/1.8)
      IF(T1.GE.TMAX)GO TO 50
      ISWTCH=0
      P2=CON(1)+CON(2)*T1+CON(3)*T1**2+CON(4)*T1**3
C     TEST IF LINES CROSS
      IF(P1.LE.P2)GO TO 60
C     NOW HAVE INTERSECTION BRACKETED
      DT=TH-T1
      DP1=P1H-P1
      DP2=P2H-P2
      SLP1=DP1/DT
      SLP2=DP2/DT
      GO TO 80
   60 P1H=P1
      P2H=P2
      TH=T1
      GO TO 50
   80 TINRST=(P2-P1+T1*(SLP1-SLP2))/(SLP1-SLP2)
      PINRST= SLP1*(TINRST-T1)+P1
      WRITE(6,501)P1,T1,P2,DT,SLP1,SLP2,TINRST,PINRST
  501 FORMAT(10X,8E10.3)
C
C     OBTAIN MOLE FRACTION OF CONDENSANT
C     NOW INTERPOLATE FOR AXIAL POSITION OF CONDENSATION
C     FIRST CALC. ACTUAL PRESSURE AND TEMP
      TI=EXP(TINRST )
      PIT = EXP(PINRST)
      PI = PIT*14.7*144./XCON
      WRITE(6,90)
   90 FORMAT(20X,31HOCONDENSATION PROPERTIES FOLLOW)
      WRITE(6,91)TI,PI
   91 FORMAT(1HO,19X,3HT2=,E10.3,2X,3HPI=,E10.3)
      X1H=PROP(1,I-1)
      SLPX=ALOG(PROP(5,I)/PROP(5,I-1))/ALOG(PROP(1,I)/PROP(1,I-1))
      ONOM=1./SLPX
```

```
      XI=X1H*EXP(ONOM*ALOG(PI/PROP(5,I-1)))
      WRITE(6,100)XI
  100 FORMAT(1H0,14X,28HSIMULANT CONDENSATION PT. IS,E10.3)
C     COMPUTE PERCENT DIFFERENCE
      DX=XSAT-XI
      DEPM = 2.*RADTHM*SQRT(AEOAT)
      DIFF = 20.*DEPM
C     DETERMINE IF ERROR ACCEPTABLE
      IF(XI.GT.XC13.AND.XSAT.GT.XC13)GO TO 200
      IF(DX.LE.DIFF) GO TO 200
      ISWTCH=1
C     IF NOT COMPUTE A DESIRED CHANGE IN TO TO ADJUST THE PT.
      GOGM1=(PROP(3,I)-1.)/PROP(3,I)
C
C     KNOWING DESIRED SATURATION POSITION A NEW PRESSURE IS COMPUTED
      PNEW= PI*EXP(SLPX*ALOG(XSAT/XI))
      DELP= PNEW-PI
      IACP=1
      TONEW= (DELP/TAB(1,5,1))**GOGM1*TAB(1,6,1)*DELP**(1./SLP1)
C     IS TONEW ACCEPTABLE
      IF(TONEW.LT.2000.)IACP=0
      WRITE(6,105)TONEW
  105 FORMAT(1H0,20X,18HNEW TO COMPUTED IS,E10.3)
  200 RETURN
      END
```

```
$IBFTC REST1   DECK
      SUBROUTINE RESET
      COMMON/TAPE/IPROT
      COMMON/PLUNMU/XC(5),PC(5),EMC(5),GMC(5),TC(5),QC(5),EMWC(5)
      COMMON/PLUMF1/PRPR(10,4),REYPLM
      COMMON/PLUMF2/PROP(10,200),IPT
      COMMON/REGION/XC11,XC12,XC13,ERRMAX,ITYPE
C     RESETS SIMULANT  PLUMF PTS. TO THOSE STATIONS
C     COMPUTED FOR PROTOTYPE CASE
      IF(IPROT.EQ.1) GO TO 40
      I=0
      J=0
    5 J=J+1
   10 I=I+1
      IF(PRPR(1,J).GT.PROP(1,I))GO TO 10
      XQ=PRPR(1,J)
      XC(J)=XQ
      SLP1=ALOG(PROP(5,I)/PROP(5,I-1))/ALOG(PROP(1,I)/PROP(1,I-1))
      PC(J)= PROP(5,I-1)*EXP(SLP1*ALOG(XQ/PROP(1,I-1)))
C
      SLP2=(PROP(4,I)-PROP(4,I-1))/(PROP(1,I)-PROP(1,I-1))
      EMC(J)= SLP2*(XQ-PROP(1,I-1))+PROP(4,I-1)
C
      SLP3=(PRPR(3,I)-PRPR(3,I-1))/(PROP(1,I)-PROP(1,I-1))
      GMC(J)=SLP3*(XQ-PROP(3,I-1))+PROP(3,I-1)
      XSIP=ALOG(PROP(5,I-1)/PROP(5,I))/ALOG(PROP(6,I-1)/PROP(6,I))
      ONOX=1.0/XSIP
      TC(J)= PROP(6,I-1)*(PC(J)/PROP(5,I-1))**ONOX
      RGC=1545./PROP(7,I-1)*32.174
      A=GMC(J)*RGC*TC(J)
      QC(J)= EMC(J)*SQRT(A)
      EMWC(J)=PROP(7,I-1)
      NPTS=3
      IF(J.EQ.NPTS)GO TO 20
      GO TO 5
   20 CONTINUE
      WRITE(6,25)
   25 FORMAT(1H0,10X,35HSIMULANT PLUME PROPERTIES AT X-CUTS)
```

```
      WRITE(6,27)
   27 FORMAT(1H0,20X,1HX,10X,2HPC,10X,1HM,10X,1HG,10X,1HT,10X,2HMW,
     110X,1HQ)
      WRITE(6,26)( XC(J),PC(J),EMC(J),GMC(J),TC(J),EMWC(J),QC(J) ,J=1,3)
   26 FORMAT(25X,7E10.3)
      GO TO 100
   40 CONTINUE
C     THE FOLLOWING SECTION PICKS OUT PROTOTYPE PTS IN REGION
      XC(1)=XC11
      XC(2)=XC12
      XC(3)=XC13
      I=0
      J=0
   45 I=I+1
   50 J=J+1
      IF(XC(I).GT.PROP(1,J))GO TO 50
      FAC1=ALOG(PROP(5,J)/PROP(5,J-1))/ALOG(PROP(1,J)/PROP(1,J-1))
      PRPR(5,I)= PROP(5,J)*EXP(FAC1*ALOG(XC(I)/PROP( 1,J-1)))
      FAC2= (PROP(4,J)-PROP(4,J-1))/(PROP(1,J)-PROP(1,J-1))
      PRPR(4,I)= PROP(4,J-1)+ FAC2*(XC(I)-PROP(1,J-1))
      FAC3= (PROP(3,J)-PROP(3,J-1))/(PROP(1,J)-PROP(1,J-1))
      PRPR(3,I)= PROP(3,J-1)+ FAC3*(XC(I)-PROP(1,J-1))
      ONOX=1./( ALOG(PROP(5,J-1)/PROP(5,J))/ ALOG(PROP(6,J-1)/PROP(6,J))
     1)
      PRPR(6,I)=PROP(6,J-1)*(PRPR(5,I)/PROP(5,J-1))**ONOX
      PRPR(7,I)=PROP(7,J-1)
      PRPR(1,I)=XC(I)
      IF(I.EQ.3) GO TO 70
      GO TO 45
   70 CONTINUE
      WRITE(6,75)
   75 FORMAT(20X,33HPROTOTYPE PLUME POINTS FOR REGION)
      WRITE(6,80)
   80 FORMAT(15X,1HX,10X,5HM NO.,10X,5HGAMMA,10X,1HP,10X,1HT,10X,2HMW)
      DO 90 IP=1,3
      WRITE(6,85)PRPR(1,IP),PRPR(4,IP),PRPR(3,IP),PRPR(5,IP),PRPR(6,IP),
     1PRPR(7,IP)
   85 FORMAT(10X,6(E10.3,4X))
   90 CONTINUE
  100 CONTINUE
      RETURN
      END
$*
$ORIGIN         C
```

```
$IBFTC TRAN    DECK
      SUBROUTINE TRANS(TE,JDUM,VIS)
C
C**   PROGRAM WHICH CALCULATES TABLE OF VISCOSITY, CP AND THERMAL
C     CONDUCTIVITY FROM THE NASA-LEWIS EQUILIBRIUM CHEMISTRY DATA
C
C    TO LESSEN THE NO. OF CHANGES THAT MUST BE MADE, THE THERMODYNAMIC
C     DATA FOR THE TRANSPORT PROPERTIES WILL BE READ FROM TAPE 12, THE
C    OLD NASA/LEWIS DATA TAPE.
C     THE THERMODYNAMIC DATA FOR THE CEC PORTION WILL BE READ FROM TAPE
C     4, THE NEW DATA TAPE GENERATED BY MCDERMIT.
C     TO MAKE THESE COMPATABLE THE CEC IS MODIFIED TO READ THE GAS NAME
C     UNDER A 2A6 FORMAT.
      DIMENSION ZETA(4),BETA(4),BETEND(4)
      COMMON/SPDATA/AA(90,5),XMF(90),XMW(90),SIGMA(90),OMEGA(90),TR,N
      COMMON/SPNAME/SPNAM1(90),SPNAM2(90),TEMP( 5, 90),IDATA,KK,KT
      COMMON/THRMTR/A(90,15)
      COMMON/MO/NUM(90)
      COMMON/GASES/TAB(3,12,13),NMIX
      DATA (BETEND(I),I=1,4)/4*6HEND
      COMMON/WRIT/IFLG1
      COMMON/COUNT/IKLUG
      IDATA=NMIX+7
      TR=TE
      REWIND 13
      IV=3
C**   LOOP WHICH CALCULATES FLOW PROPERTIES
      DO 54 J=3,IV
 1030 FORMAT(1H , (7E18.7))
      IF(TR.LT. 1.0) GO TO 9000
      KT = 0
      DO 55 K=8,IDATA
      IF(TEMP(J,K).LT..000005)GO TO 55
      IF(TEMP(J,K).GT.1.0    ) GO TO 55
      KT = KT + 1
C
C**   GAS SPECIE NAMES
C
```

```
      SPNAM1(KT) = TEMP(1,K)
      SPNAM2(KT) = TEMP(2,K)
   55 CONTINUE
      IF(KT.EQ.0) GO TO 999
C
C**   LOCAL TEMPERATURE
      IERR = 0
      CALL GTLUP(J,IERR,IFIRST)
      IF(IERR.LQ.1) GO TO 99
C
C**   CALCULATE VISCOSITY,CP,CONDUCTIVITY
C
      CALL PROPTY(   VIS,COND,CP)
      TEMP(J,IDATA+1) = VIS
      TEMP(J,IDATA+2) = COND
      TEMP(J,IDATA+3) = CP
      GO TO 54
  999 WRITE(6,1000)I,J
 1000 FORMAT(1H0,33HNO SPECIE DATA FOR ENTROPY CUT = ,I2, 17H  VELOCITY
     1CUT = ,I2)
      TEMP(J,IDATA+1) = 0.
      TEMP(J,IDATA+2) = 0.
      TEMP(J,IDATA+3) = 0.
      GO TO 54
 9000 WRITE(6,9001)
 9001 FORMAT(1H , 20HNEGATIVE TEMPERATURE )
      TEMP(J,IDATA+1) = 0.
      TEMP(J,IDATA+2) = 0.
      TEMP(J,IDATA+3) = 0.
   54 CONTINUE
   99 CONTINUE
C
      RETURN
      END
```

```
$ORIGIN         D
$IBFTC PROP     DECK
C
      SUBROUTINE PROPTY(     VISCOS,COND, CP)
C**   THIS SUBROUTINE CALCULATES THE GAS VISCOSITY, THERMAL CONDUCTIVITY
C     AND CP AS A FUNCTION OF TEMPERATURE
      DIMENSION TABLJP(131)
      DIMENSION CPR(90), XP(4,90), F(4),XA(90),D(90,90)
      COMMON/WRIT/IFLG1
      COMMON/SPDATA/AA(90,5),XMF(90),XMW(90),SIGMA(90),OMEGA(90),TR,N
C**   THIS TABLE IS THE REDUCED COLLISION INTEGRAL FROM HIRSHFELDER
      COMMON/SPNAME/SPNAM1(90),SPNAM2(90),TEMP( 5, 90),IDATA,KK,KT
C     1      THE HIRSHFELDER SYMBOL EQUALS  OMEGA***2,2
      DATA TABLJP /65.,   .3 ,    .4 ,    .5 ,    .6 ,    .7 ,    .8 ,      01150
     *    .9 ,   1.  ,   1.1 ,   1.2 ,   1.3 ,   1.4 ,   1.5 ,   1.6 ,      01160
     *   1.7 ,   1.8 ,   1.9 ,   2.0 ,   2.1 ,   2.2 ,   2.3 ,   2.4 ,      01170
     *   2.5 ,   2.6 ,   2.7 ,   2.8 ,   2.9 ,   3.0 ,   3.1 ,   3.2 ,      01180
     *   3.3 ,   3.4 ,   3.5 ,   3.6 ,   3.7 ,   3.8 ,   3.9 ,   4.0 ,      01190
     *   4.1 ,   4.2 ,   4.3 ,   4.4 ,   4.5 ,   4.6 ,   4.7 ,   4.8 ,      01200
     *   4.9 ,   5.  ,   6.  ,   7.  ,   8.  ,   9.  ,  10.  ,  20.  ,      01210
     *  30.  ,  40.  ,  50.  ,  60.  ,  70.  ,  80.  ,  90.  , 100.  ,      01220
     * 200.  , 300.  , 400.  ,                                              01230
     $                2.785 , 2.492 , 2.257 , 2.065 , 1.908 , 1.780 ,      01240
     $ 1.675 , 1.587 , 1.514 , 1.452 , 1.399 , 1.353 , 1.314 , 1.279 ,      01250
     $ 1.248 , 1.221 , 1.197 , 1.175 , 1.156 , 1.138 , 1.122 , 1.107 ,      01260
     $ 1.093 , 1.081 , 1.069 , 1.058 , 1.048 , 1.039 , 1.030 , 1.022 ,      01270
     $ 1.014 , 1.007 ,  .9999,  .9932,  .9870,  .9811,  .9755,  .9700,      01280
     $  .9649,  .9600,  .9553,  .9507,  .9464,  .9422,  .9382,  .9343,      01290
     $  .9305,  .9269,  .8963,  .8727,  .8538,  .8379,  .8242,  .7432,      01300
     $  .7005,  .6718,  .6504,  .6335,  .6194,  .6076,  .5973,  .5882,      01310
     $  .5320,  .5016,  .4811/                                              01320
C
C     THE AA ARRAY IS DEFINED AS THE FOLLOWING
C **  THIS DATA TAKEN FROM NASA LEWIS THERMOCHEMISTRY DATA DECK  **
C
C     1     THE FIRST FIVE NUMBERS OF EACH TWO CARD SET
C     2     ARE POLYNOMINAL COEFFICIENTS OF A CURVE FIT
C     3     OF CP/R FOR A TEMPERATURE RANGE DEPENDING ON TK
```

```
C       XMF=MASS FRACTION
C       XMW=MOLECULAR WEIGHT
C       CPR=CPAR
C       RU=UNIVERSAL GAS CONSTANT
C       VISCOS=VISCOSITY
C       COND=THERMAL CONDUCTIVITY
C       CP=SPECIFIC HEAT AT CONSTANT PRESSURE
        TK = TR/ 1.8                                                    01510
        RU = 1.98726                                                    01520
        DO 840 I = 1, N                                                 01530
        XP(4,  I) = XMW(I)                                              01560
        CPR(I) = AA(I,1)                                                01600
        DO 830 J = 2, 5                                                 01610
        AT = AA(I,J)                                                    01620
        DO 820 JJ= 2,J                                                  01630
  820 AT = AT * TK                                                      01640
  830 CPR(I) = CPR(I) + AT                                              01650
        XP(3,I) = CPR(I)                                                01660
  840  CONTINUE                                                         01670
        DO 850 I = 1, N                                                 01680
        TRED   =  TK   / OMEGA(I)                                       01690
        CALL ONEVAR( TRED, 2, TABLJP, 1, 131, OMERED)                   01700
        IF(IFLG1.EQ.0)GO TO 191
        WRITE(6,1032)TRED,OMERED,I
 1032 FORMAT(1H0, 6HTRED =,E15.7,5X, 8HOMERED =, E15.7, 5X, 3H I=,I3)
  191 CONTINUE
        XP(1,  I)=266.93 *10.**(-7)*SQRT(XMW(I)*TK  )/(SIGMA(I)**2*OMERED)  01710
  850 XP(2,  I) =(RU/XMW(I))*(3.75 +1.32*(CPR(I)- 2.5))*XP(1,  I)       01720
        IF(IFLG1.EQ.0)GO TO 192
        WRITE(6,1035)
 1035 FORMAT(1H , 35HRESULTS OF TRANSPORT PROPERTY CALCS,//, 6HSPECIE,7X
     1, 6HVISCOS,8X, 4HCOND,10X, 2HCP, 12X, 7HMOL, WT,7X, 9HMOL FRACT,
     2 5X, 5HOMEGA,  9X, 5HSIGMA, 9X,11HTEMP(DEG K),//)
  192 CONTINUE
        DO 600 I=1,N
        IF(IFLG1.EQ.0)GO TO 193
  600 WRITE(6,1040) SPNAM1(I),SPNAM2(I),(XP(K,I),K=1,4),XMF(I),OMEGA(I),
     1 SIGMA(I),TK
```

```
 1040 FORMAT(1HO, 2A6,1X,(8(E12.5,2X)))
  193 CONTINUE
  900 CONTINUE                                                          01730
      DO 500 K = 1,4                                                    01740
C                                                                       01750
C FOR K = 1  VISCOSITY OF MIXTURE CALCULATED                            01760
C     K = 2  CONDUCTIVITY OF MIXTURE CALCULATED                         01770
C     K = 3  CP OF MIXTURE CALCULATED                                   01780
C     K = 4  MOLE WEIGHT OF MIXTURE CALCULATED                          01790
C                                                                       01800
      VISCOS = 0.                                                       01810
      COND   = 0.                                                       01820
      CP     = 0.                                                       01830
      OLWT = 0.                                                         01840
      F(K) = 0.                                                         01850
      DO 400 I=1,N                                                      01860
      XA(I) = 0.0                                                       01870
      IF (K.EQ.4) GO TO 320
      DO 300 J=1,N                                                      01880
      IF (J .EQ. I) GO TO 300                                           01890
      D(I,J) = .376*(1. + SQRT(XP(K,I) / XP(K,J)) * (XMW(J)/XMW(I))     01900
     1          **.25)**2*SQRT(XMW(J)/(XMW(I)+XMW(J)))                  01910
      XA(I)  = XA(I) + XMF(J) * D(I,J)
  300 CONTINUE                                                          01930
      IF(XMF(I).LT..000001) GO TO 400                                   01940
  310 F(K) = F(K) + (XMF(I) * XP(K,I)) / (XMF(I) + XA(I))               01950
      GO TO 400
  320 F(K) = F(K) + XP(K,I)*XMF(I)
  400 CONTINUE                                                          01960
  500 CONTINUE                                                          01970
C     UNITS-POISES
      VISCOS=F(1)
C     UNITS-ENGLISH
      COND   = F(2)
C     UNITS-BTU/LBM/DEG-R
      CP     = F(3)  * RU / F(4)                                        02000
      OLWT   = F(4)                                                     02010
      RETURN                                                            02020
      END                                                               02030
```

```
$IBFTC ONEV     DECK
       SUBROUTINE ONEVAR (ARGUMT,NXDIR, TABLE, NOTAB, NX, OUTPUT)          02050
C                                                                           2060
C  ONEVAR IS AN INTERPOLATION ROUTINE - ONE FUNCTION OF ONE                 02070
C    ARGUMENTS OF THE SUBROUTINE ARE AS FOLLOWS                             02080
C      ARGUMT   = INPUT INTERPOLATION ARGUMENT (X)                          02090
C      NXDIR    = TYPE OF INTERP. 1 FOR LINEAR, 2 FOR QUAD.                 02100
C      TABLE    = SET OF X VALUES FOLLOWED BY THE Y VALUES                  02110
C      OUTPUT   = INTERPOLATED VALUE OF Y = F(X)                            02120
C      NER      = ERROR CODE                                                02130
C                 1 = OK, INTERPOLATION SUCCESSFUL.                         02140
C                 2 = OFF CHART LOW END. MIN. VAL. SUBSTITUTED              02150
C                 3 = OFF CHART HIGH END. MAX. VAL. SUBSTITUTED             02160
C                 4 = NO. OF X ENTRIES IS NOT 2 TO 15 (IF NXDIR             02170
C                     IS 1). OR, IT IS NOT 3 TO 15 (IF NXDIR                02180
C                     IS 2).                                                02190
C                 5 = X ENTRIES NOT IN ASCENDING ORDER.                     02200
C                                                                           02210
C      TABLE IS LOADED AS     LOC.      VALUE                               02220
C                         TABLE(1)      NO. OF X VALUES                     02230
C                         TABLE(2)      X(1)                                02240
C                                                                           02250
C                               ETC                                         02260
C                         TABLE(N+1)  X(N)                                  02270
C                         TABLE(N+2)  Y(1)  WHERE  Y = F(X)                 02280
C                                                                           02290
C                               ETC                                         02300
C                         TABLE(N+1+N) Y(N)                                 02310
C                                                                           02320
       DIMENSION TABLE(NX)                                                  02330
       NOENTR = INT(TABLE(1))                                               02340
       N = NOENTR                                                           02350
       NER = 1                                                              02360
       IF (NXDIR-1) 1,1,2                                                   02370
     1 IF (NOENTR-2) 4,3,3                                                  02380
     2 IF (NOENTR-3) 4,3,3                                                  02390
     3 IF(NXDIR + 1 - NOENTR ) 5, 9, 4                                      02400
     4 NER = 4                                                              02410
```

```
      GO TO 701                                                          02420
    5 IF (ARGUMT-TABLE(2)) 6,7,10                                        02430
    6 NER = 2                                                            02440
      GO TO (23, 32), NXDIR                                              02450
    7 NER = 1                                                            02460
    8 IOUT = 2                                                           02470
      GO TO 700                                                          02480
    9 GO TO (23, 32), NXDIR                                              02490
   10 IF (TABLE(NOENTR+1)-ARGUMT)11,13,16                                02500
   11 NER = 3                                                            02510
      I = N - 1                                                          02520
      GO TO (25, 31),NXDIR                                               02530
   13 NER = 1                                                            02540
   14 IOUT = NOENTR+1                                                    02550
   15 GO TO 700                                                          02560
C AT THIS STAGE OF THE GAME, ERROR CONDITIONS 2,3,4 HAVE                 02570
C BEEN TESTED FOR AND HAVE BEEN PASSED.                                  02580
   16 DO 100 JK=1, NOENTR                                                02590
      I = JK                                                             02600
      IF (I-1) 20,20,17                                                  02610
   17 IF (TABLE(I+1)-TABLE(I))18,18,20                                   02620
   18 NER = 5                                                            02630
      GO TO 701                                                          02640
   20 IF (TABLE(I+1)- ARGUMT) 99,21,24                                   02650
   99 IF (I .GE. N) GO TO 11                                             02660
  100 CONTINUE                                                           02670
   21 NER = 1                                                            02680
      IOUT = I+1                                                         02690
      GO TO 700                                                          02700
   23 I = 2                                                              02710
   24 IF (NXDIR-1) 25,25,29                                              02720
   25 ION = I + N                                                        02730
      OUTPUT = TABLE(ION )+ (ARGUMT - TABLE(I)) * (TABLE                 02740
     1(ION+1)- TABLE(ION ))/(TABLE(I+1)-TABLE(I))                        02750
      GO TO 701                                                          02760
   29 IF (NOENTR - I) 31, 30, 33                                         02770
   30 I = I-1                                                            02780
      GO TO 31                                                           02790
```

```
     32 I = 2                                                                  02800
     33 IF (I .EQ. 1) I = 2                                                    02810
     31 ION = I + N                                                            02820
        CA=(TABLE(ION)*(ARGUMT-TABLE(I+1))*(ARGUMT- TABLE(I+2)))
        CB=(TABLE(I)-TABLE(I+1))
        CD=(TABLE(I)-TABLE(I+2))
        CE=((TABLE(ION+1)*(ARGUMT - TABLE(I)))*(ARGUMT-TABLE(I+2)))
        CF=((TABLE(I+1)-TABLE(I))*(TABLE(I+1)-TABLE(I+2)))
        OUTPUT= (CA)/(CB * CD)+(CE)/(CF) + (TABLE(ION+2)*(ARGUMT -
       1TABLE(I))  * (ARGUMT - TABLE(I+1)))/((TABLE(I+2)-                     02880
       1TABLE(I))   *(TABLE(I+2) - TABLE(I+1)))                               02890
        GO TO 701                                                             02900
    700 IOUT = IOUT + N                                                       02910
        OUTPUT = TABLE(IOUT)                                                  02920
    701 IF (NER - 2) 800, 707, 706                                            02930
    706 IF (NER - 4) 707, 711, 714                                            02940
    707 GO TO 800                                                             02950
    711 WRITE(6,712) NOTAB                                                    02960
    712 FORMAT(1H ,28HTOO FEW ENTRIES IN TABLE NO., I4)                       02970
        GO TO 800                                                             02980
    714 WRITE (6, 715) NOTAB                                                  02990
    715 FORMAT(1H ,57HENTRIES ARE NOT IN MONOTOMIC ASCENDING ORDER IN TABL    03000
       1E NO.,I4)                                                             03010
    800 RETURN                                                                03020
        END                                                                   03030
$ORIGIN         D
```

```
$IBFTC GTLU     DECK
      SUBROUTINE GTLUP(J,IERR,IFIRST)
C
C**   THIS SUBROUTINE DOES A TAPE LOOK UP TO OBTAIN DATA REQUIRED FOR
C     COMPUTATION CP,MU AND K
      DIMENSION DDD(90,5)
      COMMON/WRIT/IFLG1
      COMMON/DRAY/B(5,100),KD
      DIMENSION TITLT(4),D(5),DD(15,4),TITLE(4),TEND(4)
      COMMON/SPDATA/AA(90,5),XMF(90),XMW(90),SIGMA(90),OMEGA(90),TR,N
      COMMON/SPNAME/SPNAM1(90),SPNAM2(90),TEMP( 5, 90),IDATA,KK,KT
      COMMON/THRMTR/A(90,15)
      COMMON/MO/NUM(90)
      COMMON/COUNT/IKLUG
      DATA(TEND(I),I=1,4)/4*6HEND    /
      DATA(TITLE(I),I=1,4)/6HSPECIE,6HDATA F,6HOR TRA,6HNSPROP/
      IF(IFIRST.EQ.0.AND.J.EQ.3) GO TO 6
      IF(J.GT.3) GO TO 90
      IF(IFIRST.EQ.1)GO TO 10
      IF(IKLUG.GT.0)GO TO 6
      IKLUG=1
      IF(IFLG1.EQ.0)GO TO 191
      WRITE(6,3)
    3 FORMAT(39HOB ARRAY CONTAINING SOME DATA FOR TRANS)
      WRITE(6,4)((B(I,JD),I=1,5),JD=1,KD)
    4 FORMAT(5X,2A6,3E10.3)
  191 CONTINUE
    6 CONTINUE
      IFIRST = 1
      DO 9 KRD=1,KD
      DO 15 I=1,5
   15 DDD(KRD,I)=B(I,KRD)
    9 CONTINUE
   10 CONTINUE
      KK=0
      KRD=KD
      DO 25 I=1,KRD
      DO 17 III=1,5
```

```
   17 D(III) = DDD(I,III)
      DO 20 JJ =8,IDATA
      IF ( D(1).EQ.TEMP(1,JJ))GO TO 11
      GO TO 20
   11 IF (D(2).EQ.TEMP(2,JJ))GO TO 21
   20 CONTINUE
      GO TO 25
   21 KK=KK+1
      NUM(KK) = JJ
      DO 22 L=1,5
   22 A(KK,L)= D(L)
      IF(IFLG1.EQ.0)GO TO 192
       WRITE(6,200)
  200 FORMAT(39HOA ARRAY CONTAINING GAS DATA TO BE USED)
      WRITE(6,201)KK,(A(KK,L),L=1,5)
  201 FORMAT(4X,I2,2X,2A6,3F10.3)
  192 CONTINUE
      IF(KK+7.EQ.IDATA) GO TO 50
   25 CONTINUE
   50 NUMFND = 0
C
C     FIND AND FILL IN THERMO DATA
C
   51 READ(13) (D(I),I=1,5),((DD(I,IJ),I=1,9),IJ=1,2)
      IF(IFLG1.EQ.0)GO TO 193
      WRITE(6,500)(D(I),I=1,5)
  500 FORMAT(23HOD ARRAY READ FROM TAPE,5E10.3)
  193 CONTINUE
      DO 70 JJ=1,KK
      IF(D(1).EQ.TEND(1)) GO TO 80
      IF(D(1).NE.A(JJ,1)) GO TO 70
      IF(D(2).EQ.A(JJ,2)) GO TO 72
   70 CONTINUE
      GO TO 51
   72 LI =5
      DO 78 NN=1,2
      DO 77 LL=3,7
      LI=LI+1
```

```
   77 A(JJ,LI) = DD(LL,NN)
   78 CONTINUE
      IF(IFLG1.EQ.0)GO TO 194
      WRITE(6,202)D(1),D(2)
  202 FORMAT(5X,2A6)
      WRITE( 6,203)((A(JJ,LI),LI=6,15))
  203 FORMAT(1H0,     10E10.3)
  194 CONTINUE
      NUMFND = NUMFND+1
      IF(NUMFND.EQ.KK) GO TO 90
      GO TO 51
   80 IF(NUMFND.EQ.KK) GO TO 90
      WRITE(6,81)
   81 FORMAT(1H0,50HNOT ALL SPECIES FOUND ON THERMO-CHEM PRODUCT TAPE )
   90 N=0
      M = 1
      REWIND 13
   91 DO 96 NN=1,KK
      IF(SPNAM1(M).NE.A(NN,1)) GO TO 96
      IF(SPNAM2(M).EQ.A(NN,2)) GO TO 98
      GO TO 96
   98 TK = TR/1.8
      N = N + 1
C
C**   SET ARRAY CONTAINING CONSTANTS FOR GAS CALCULATIONS
C
      JJ=0
      IF(TK.GT.999.) GO TO 110
      DO 105 LL = 11,15
      JJ= JJ+1
  105 AA(N,JJ) = A(NN,LL)
      GO TO 120
  110 DO 115 LL = 6,10
      JJ=JJ+1
  115 AA(N,JJ) = A(NN,LL)
  120 NN8 = NUM(NN)
C
C**   MOLE FRACTIONS
```

```
      XMF(N) = TEMP(J,NN8)
      SPNAM1(N) = A(NN,1)
      SPNAM2(N) = A(NN,2)
C**   SPECIES MOLECULAR WEIGHT
      XMW(N) = A(NN,3)
      SIGMA(N)=A(NN,4)
      OMEGA(N)=A(NN,5)
      IF(IFLG1.EQ.0)GO TO 195
      WRITE(6,300)J,NN,NN8,TEMP(J,NN8)
  300 FORMAT(10H0NUM CHECK,2X,3I5,2X,E10.3)
  195 CONTINUE
      GO TO 97
   96 CONTINUE
   97 IF (M .EQ. KK) GO TO 9999
      M = M + 1
      GO TO 91
 9999 RETURN
      END
```

```
$IBFTC BDATA   DECK
      BLOCK DATA
      COMMON/DRAY/B(5,100),KD
      DATA KD/45/
      DATA ((B(I,J),I=1,5),J=1,19)/
     16HAL      ,     6H       ,          26.98  ,    2.655 ,   2750.0        ,
     26HALCL    ,     6H       ,          62.444 ,    3.578 ,    972.0        ,
     36HALCL3   ,     6H       ,         133.55  ,    5.127 ,    472.0        ,
     46HALF     ,     6H       ,          45.98  ,    3.148 ,    556.0        ,
     56HALF3    ,     6H       ,          83.98  ,    4.198 ,   1846.0        ,
     66HALN     ,     6H       ,          40.99  ,    3.369 ,   2682.0        ,
     76HALO     ,     6H       ,          42.98  ,    3.204 ,    542.0        ,
     86HALS     ,     6H       ,          59.05  ,    3.73  ,   1526.0        ,
     96HAL2     ,     6H       ,          53.96  ,    2.94  ,   2750.0        ,
     A6HAR      ,     6H       ,          39.944 ,    3.542 ,     93.3        ,
     B6HAS1H3   ,     6H       ,          77.94  ,    4.145 ,    259.8        ,
     C6HB       ,     6H       ,          10.82  ,    2.265 ,   3331.0        ,
     D6HBBR3    ,     6H       ,         250.57  ,    5.439 ,   430.0         ,
     E6HBCL     ,     6H       ,          46.28  ,    3.318 ,   1026.0        ,
     F6HBCL2    ,     6H       ,          81.73  ,    4.222 ,    682.0        ,
     G6HBCL3    ,     6H       ,         117.19  ,    5.127 ,    337.7        ,
     $6HCCLF3   ,     6H       ,         104.47  ,    4.96  ,    188.0        ,
     $6HCF4     ,     6H       ,          88.01  ,    4.662 ,    121.0        ,
     $6HCHF3    ,     6H       ,          70.02  ,    4.33  ,    240.0/
      DATA ((B(I,J),I=1,5),J=20,38)/
     H6HCH4     ,     6H       ,          16.04  ,    3.758 ,    148.6        ,
     I6HCO      ,     6H       ,          28.01  ,    3.690 ,    91.7         ,
     J6HCOS     ,     6H       ,          60.08  ,    4.13  ,    336.0        ,
     K6HCO2     ,     6H       ,          44.01  ,    3.941 ,    195.2        ,
     L6HCS      ,     6H       ,          44.08  ,    4.216 ,    199.4        ,
     M6HCL      ,     6H       ,          35.457 ,    3.613 ,    130.8        ,
     N6HCL2     ,     6H       ,          70.91  ,    4.217 ,    316.0        ,
     O6HH       ,     6H       ,           1.008 ,    2.708 ,     37.0        ,
     P6HH2      ,     6H       ,           2.016 ,    2.827 ,     59.7        ,
     Q6HHCL     ,     6H       ,          36.47  ,    3.339 ,    344.7        ,
     R6HH2O     ,     6H       ,          18.02  ,    2.641 ,    809.1        ,
     S6HHS      ,     6H       ,          33.07  ,    3.673 ,     86.4        ,
     T6HH2S     ,     6H       ,          34.08  ,    3.623 ,    301.1        ,
```

```
      U6HN2     ,     6H        ,          28.02   ,    3.798 ,     71.4          ,
      V6HNH3    ,     6H        ,          17.03   ,    2.90  ,    558.3          ,
      W6HNO     ,     6H        ,          30.01   ,    3.492 ,     16.7          ,
      $6HN2O    ,     6H        ,          44.02   ,    3.828  ,   232.4          ,
      *6HNE     ,     6H        ,          20.183  ,    2.82  ,    32.8           ,
      X6HO      ,     6H        ,          16.0    ,    3.05  ,    106.7          /
       DATA((B(I,J),I=1,5),J=39,45)/
      Y6HO2     ,     6H        ,          39.0    ,    3.467 ,    106.7          ,
      Z6HOH     ,     6H        ,          17.01   ,    3.147 ,     79.8          ,
      *6HS      ,     6H        ,          32.066  ,    3.839 ,    847.0          ,
      $6HSF6    ,     6H        ,         146.07   ,    5.128  ,   222.1          ,
      *6HSO     ,     6H        ,          48.07   ,    3.993 ,    301.0          ,
      *6HSO2    ,     6H        ,          64.07   ,    4.112 ,    335.4          ,
      *6HS2     ,     6H        ,          64.13   ,    4.519 ,    847.0/
       END
$*
$ORIGIN         B
```

```
$IBFTC SOUR     DECK
       SUBROUTINE SOURCE(IDUM,ISCON)
       COMMON/WRIT/IFLG1
       DIMENSION SAVEA(16)
       DATA (SAVEA(K),K=1,16) /16*0./
    99 FORMAT(1H1)
   100 FORMAT(4X2HS2,7X7HMACH NO5X5HRE NO5X7H GAMMA 2X10HKNUDSEN NO5X,3H
      1TO5X1HT9X2HPO10X1HP)
   200 FORMAT(1HO,10E11.4,2X,I3)
   300 FORMAT(1H020X,32HVIBRATIONAL    ENERGY MODE FROZEN)
   400 FORMAT(1H052X,32HROTATIONAL     ENERGY MODE FROZEN)
   500 FORMAT(1H084X,32HTRANSLATIONAL ENERGY MODE FROZEN)
       COMMON/PLUMF2/PROP(10,200),IPT
       COMMON/GASES/TAB(3,12,13),NMIX
       COMMON/GASCON/GAMA,R,T0,P0,EM,RHO,T,WM ,Q
       COMMON/GEOM/AT,RADTHT,AEOAT,ANGLP,REYNP
       COMMON/LIP/THET,PI02
       COMMON/EXCON/PEX,EMU
       COMMON/TAPE/IPROT
       EQUIVALENCE(GAMA,GAMMA)
       IPT=0
       IFREZ=0
       ITC1=0
       ITC2=0
       LPAGE=1
       POWER=.95
       CNLOCL=0.
       GMT=1.4
       ISCON=0
       PI=3.1415926536
       PI02=PI/2.
       REXT=RADTHT*SQRT(AEOAT)
C      FIRST COMPUTE LIP EXPANSION ANGLE
       RE=RADTHT*SQRT(AEOAT)
       ANGLP=ANGLP/57.29578
       P=PEX
       CALL TABLE(P,1)
       QE=Q
```

```
      RHOEX=RHO
      WRITE(6,1022)P   ,EM,GAMA,RHOEX,QE
 1022 FORMAT(10HOEXIT PROP,5E10.3)
      EM1=EM
      VNU=PI02*(SQRT((GAMA+1.)/(GAMA-1.))-1.)
      VN1= SQRT((GAMA+1.)/(GAMA-1.))*ATAN(SQRT((GAMA-1.)/(GAMA+1.)
     $*(EM*EM-1.)))-ATAN(SQRT(EM*EM-1.))
      DELTHT=VNU-VN1
      THET=DELTHT+ANGLP
      WRITE(6,9000)GAMA,VNU,THET
 9000 FORMAT(6HOGAMA=E10.3,4HVNU=E10.3,5HTHET=E10.3)
C     TEST IF THET GT 90.
      IF(THET.GE.PI02)GO TO 5
      X=-RE/TAN(THET)
      GO TO 15
    5 CONTINUE
      IF(THET.EQ.0.)GO TO 10
      THT=THET-PI02
      WRITE(6,9001)THT
 9001 FORMAT(5HOTHT=E10.3)
      X=RE*TAN(THT)
      GO TO 15
   10 X=0.
   15 CONTINUE
      WRITE(6,904)X,THET
  904 FORMAT(1H027HORIGIN OF SOURCE FLOW AT X=,E10.3,5X,11HWITH THETA=,E
     110.3)
      P1=P
      P2=P
      P01=TAB(1,5,1)
      T01=TAB(1,6,1)
      FUG=2.*THET
      FUG =2.*PI*(1.-COS(THET))
      PSTAR=TAB(1,5,2)
      CALL TABLE(PSTAR,1)
      RSTAR=RHO
      QSTAR=Q
      WFSTAR=RSTAR*QSTAR*AT
```

```
      WRITE(6,1023)WFSTAR,RSTAR,QSTAR
 1023 FORMAT(1H0,11HTHROAT PROP,3E10.3)
      WRITE(6,99)
      WRITE(6,100)
      SREF =2.*RE
      SST = .25
      IF(IPROT.EQ.1)SST=1.0
       S1=X
      S2 =0.
      AEXT = AT*AEOAT
  585 S2 = S2 + SST
      SSQR = FUG*S2*S2
      IF(SSQR.LE.AEXT)GO TO 585
      S2 = S2 +SREF
      PINC=-.09*P
   17 CONTINUE
      SAVEA(2)=PINC
      SAVEA(1)=1.0
      TOL=.05*WFSTAR
C     THIS SECTION COMPUTES GAS PROPERTIES UNTIL FREEZING DETECTED
C
   18 CONTINUE
      IF(P2.LE.0.)GO TO 32
      GO TO 37
   32 CONTINUE
      P2=P2-.95*PINC
      PINC=.1*PINC
      SAVEA(2)=PINC
   37 CONTINUE
      IF(CNLOCL.GT.1./500.)GO TO 19
C     USE P TO CALL TABLE
      CALL TABLE(P2,1)
       GO TO 89
   19 POP=P2/P0
      RGK=1545.*32.174/TAB(1,7,1)
      T=T0*(P2/P0)**((GAMA-1.)/GAMA)
      TOVT=T0/T
      SOS=SQRT(GAMA*RGK*T)
```

```
      FM=SQRT((TOVT-1.)/((GAMA-1.)/2.))
      Q=EM*SOS
      RHO=P2*32.174/(T*RGK)
   89 CONTINUE
      WF2=WFDOT(P2,RHO,Q,THFT,S2)
      FP=WFSTAR-WF2
      GO TO 1776
      WRITE(6,91)WF2,P2,RHO,Q,S2,GAMA,EM,T
   91 FORMAT(1H0,4HWF2=E10.3,3HP2=E10.3,4HRHO=E10.3,2HQ=E10.3,3HS2=E10.3
     $,5HGAMA=E10.3,3HEM=E10.3,2HT=E10.3)
      WRITE(6,92)SAVEA(2),PINC
   92 FORMAT(1H0,5HSAVE=E10.3,5HPINC=E10.3)
      WRITE(6,50)TOL
   50 FORMAT(5X,4HTOL=,E10.3)
 1776 CONTINUE
      CALL ITSUB(FP,P2,SAVEA,TOL,199)
      II=SAVEA(1)+.1
      N1=SAVEA(3)+.1
      GO TO (18,18,18,18,22,23),II
   23 WRITE(6,600)S2  ,P2,FP
  600 FORMAT(24H0ITSUB WILL NOT CONVERGE,1X,5HS2  =,E12.5,1X,2HP=,E12.5,
     11X,3HFP=,E12.5)
      ISCON=1
      GO TO 40
   22 CONTINUE
      PINC=.09*P2
 4500 FORMAT(8H0CNLOCL=E10.3)
      DS=S2-S1
C     EM1 SAVED FROM PREVIOUS POINT CALCULATION
   70 CONTINUE
      EM2=EM
   80 CONTINUE
      GP102=(GAMA+1.)/2.
      ONOGM1=1./(GAMA-1.)
      ROUSTR=P0/(R*T0)*((GP102**(-ONOGM1)))*SQRT (2.0*GAMMA*R*T0/(GAMMA+
     $1.0))
      T02=T0
      SBAR=(S2+S1)/2.
```

```
      EMBAR=(EM1+EM2)/2.
      VIS=1.36E-9*(T/1.8)**POWER
      RE=ROUSTR/(VIS*SBAR**2)
      DLOGT=ALOG(T02/T01*(2.+(GAMMA-1.)*EM1**2)/(2.+(GAMMA-1.)*EM2**2))
      DLTDS=ABS(DLOGT/DS)
      CNLOCL=(2.51*3.14*GAMMA)*((EMBAR*EMBAR)/RE)*DLTDS
      IF(LPAGE.LT.55)GO TO 55
      LPAGE=1
      WRITE(6,99)
      WRITE(6,100)
   55 CONTINUE
      WRITE(6,200) S2,EM2,RE,GAMMA,CNLOCL,T0,T,P0,P2
      LPAGE=LPAGE+2
      IPT=IPT+1
C     THE FOLLOWING STATEMENTS STORE PLUME PROPERTIES IN PROP ARRAY
      PROP(1,IPT)=S2/(2.*REXT)
      PROP(2,IPT)=SSQR
      PROP(3,IPT)=GAMA
      PROP(4,IPT)=EM2
      PROP(5,IPT)=P2
      PROP(6,IPT)=T
      PROP(7,IPT)=WM
      GO TO 30
      IF(CNLOCL.LT.1./500.)GO TO 30
      IFREZ=1
C     CALCULATION WITH VIBRATIONAL ENERGY MODE FROZEN
      GAMMA=1.4
      GM102=(GAMMA-1.)/2.
      ONOGM1=1./(GAMMA-1.)
      GOGM1=GAMMA*ONOGM1
      ITC1=ITC1+1
      IF(ITC1.EQ.1)T0=T*(1.+GM102*EM2*EM2)
       P0=P2*(T0/T)**GOGM1
      WRITE(6,300)
      IF(CNLOCL.LT.1./5.  )GO TO 30
C     CALCULATION WITH VIBRATIONAL AND ROTATIONAL ENERGY MODE FROZEN
      PINC=.07*P2
      CK=CNLOCL
```

```
      GAMMA= -.000567*CK**3 +.00868*CK**2 -.003404*CK +1.4003
      IF(CNLOCL.GE.10.)GAMMA=1.667
      ONOGM1=1./(GAMMA-1.)
      GOGM1=GAMMA*ONOGM1
      GM102=(GAMMA-1.)/2.
      IF(GAMMA.LE.1.667)T0=T*(1.+GM102*EM2*EM2)
      P0=P2*(T0/T)**GOGM1
      WRITE(6,400)
      IF(CNLOCL.LT..8)GO TO 30
C     CALCULATION WITH VIBRATIONAL,ROTATIONAL AND TRANSLATIONAL ENERGY
C     MODE FROZEN
      WRITE(6,500)
   30 EM1=EM2
      T01=T02
      S1=S2
      STRECH=1.0
      DELTS=SREF
      S2=S2+DELTS
      IF(EM2.GE.100.)GO TO 40
      IF(IPT.GE. 75)GO TO 40
      GO TO 17
   40 CONTINUE
      RETURN
      END
```

```
$IBFTC WDOT1    DECK
       FUNCTION WFDOT(P0,R0,Q0,THTM,R)
       PI=3.14159265
       TWOPI=2.*PI
       PIO2=PI/2.
C
       DELTHT=THTM/20.
       THETA=0.
       AREA=0.
       DO 20 J=1,20
       I1=J
       I2=J+1
       THETA=THETA
       CR=(COS(PIO2*THETA/THTM))**7
       CV=1.
       SA=SIN(THETA)
       F1   =CR*CV*SA
       THETA=THETA+DELTHT
       CR=(COS(PIO2*THETA/THTM))**7
       CV=1.
       SA=SIN(THETA)
       F2   =CR*CV*SA
       A=.5*DELTHT*(F1+F2)
   20  AREA=AREA+A
       WFDOT=TWOPI*R0*Q0*R**2*AREA
       RETURN
       END
```

```
$IBFTC ADJUS1
      SUBROUTINE ADJUST(      NOK,KAZE)
      COMMON/CHANGE/PC11,PC21,PC22,PC31,PC32,PC33,PNW,TNW,DELM,DELMN,
     $DELREY
      COMMON/AVE/EMM,EMWM,HM,HOM,GM,SLP1,SLP2
      COMMON/GASES/TAB(3,12,13),NMIX
      COMMON/CHAMB/PCHAMI,TCHAMI,PMAX,TMAX
      COMMON/PLUNMU/XC(5),PC(5),EMC(5),GMC(5),TC(5),QC(5),EMWC(5)
      COMMON/PLUMF1/PRPR(10,4),REYPLM
      COMMON/MOLWT/SA,SB,SC
      COMMON/REGION/XC11,XC12,XC13,ERRMAX,ITYPE
      COMMON/EXCON/PEX,EMU
      COMMON/GEOM/AT,RADTHT,AEOAT,ANGLP,REYNP
      LOGICAL KAZE
      PI02=3.1415927/2.0
      NOK=0
       GO TO(300,310,320),ITYPE
  300 CONTINUE
C     COMPUTE MACH NO. CHANGE FOR MOMENTUM FLUX ERROR
      P=PC(2)
      G=GMC(2)
      DEM = SQRT(ABS(DELM)/(P*G))
      IF(DELM.LT.0.) SIGN = -1.0
      IF(DELM.GT.0.) SIGN =+1.0
      DEM = SIGN*DEM
      GO TO 340
  310 CONTINUE
      DEM=DELM
      GO TO 340
  320 CONTINUE
C     COMPUTE MACH NO. CHANGE FOR REYNOLDS NO. ERROR
      GO2= (GMC(2)-1.)/2.
      EMF= (1.+GO2*EMC(2)*EMC(2))
      EGX=-1.*(3.*GMC(2)-1.)/(2.*(GMC(2)-1.))
      R=1545.*32.174/EMWC(2)
      D= 2.*RADTHT*SQRT(AEOAT)
      VISCOS=1.36E-09*(T/1.8)**.95
      PTL= PCHAMI*SQRT(GMC(2)/(R*TCHAMI))*D/VISCOS
```

```
      DEM=DELRLY/(PTL*(EMF)**EGX+EMC(2)*EMC(2)*EGX*EMF**(EGX-1.)*(GMC(2)-1.))
     $-1.))
  340 CONTINUE
      KAZE=.FALSE.
C     COMPUTE MEAN PROPERTIES FOR GAS MIXTURE UNDERGOING TESTING
      CALL MEAN(DEM,P)
C     COMPUTE CHANGE FOR MOLECULAR WT.
      HOH=HM/HOM
      SH=SLP1/HM
      GM2 =(GM-1.)/2.
      ONOM =1./EMWM
      GF1= SQRT((GM-1.)/(GM+1.))
      GF2 = 1./(GM-1.)**2
      AG =PI02*GF1*GF2/THET
      DELMW=(2.* DEM/EMM)/(ONOM+2.*HOH*(-SH+GM2*EMM**2*(SH-ONOM) +SLP2*
     1AG) +2.*SH-2.*ONOM-2.*SLP2*AG -SLP2/GM-SLP1/HM)
      DELMW = -1.0*DELMW
      WRITE(6,5)DELMW
    5 FORMAT(33H0COMPUTED CHANGE IN MOLECULAR WT=,E10.3)
      WMN=TAB(1,7,1)+DELMW
      CHCK = TAB(2,7,1)/TAB(3,7,1)
      IF(CHCK.GT.1.) GO TO 150
      WM1 =TAB(2,7,1)
      WM2 = TAB(3,7,1)
  150 WM1 = TAB(3,7,1)
      WM2 = TAB(2,7,1)
  160 CONTINUE
C     TEST IF DELMW POSSIBLE
      IF(1.05*WM1.GT.WMN)GO TO 50
      IF(.95*WM2.LT.WMN)GO TO 70
      IF(NMIX.EQ.3) GO TO 20
      X1P = SA*(SB/WMN-1.)/(SB-SA)
      X2P= 1.-X1P
      WRITE(6,10)X1P,X2P
   10 FORMAT(30HONEW MIXTURE RATIOS ARE,  X1P=,E10.3,2X,4HX2P=,E10.3)
C     BINARY MIXTURE
      PC21=X1P
      PC22=X2P
```

```
      IF(X1P.LE.0..OR.X2P.LE.0.)GO TO 30
      TNW=TAB(1,6,1)/1.8
      PNW=TAB(1,5,1)/144.
      GO TO 200
C     IF NEW MIXTURE PHYSICALLY IMPOSSIBLE . COME HERE
   30 CONTINUE
      WRITE(6,31)X1P,X2P
   31 FORMAT(5X,4HX1P=,E10.3,5X,4HX2P=,E10.3,5X,19HCHANGE BINARY GASES)
      KAZE=.TRUE.
      NOK=1
      GO TO 110
   20 CONTINUE
C     TERNARY MIXTURES
      FC=PC33
      FA=(1.-FC*WMN/SC-(1.-FC)*WMN/SB)/(WMN/SA-WMN/SB)
      FB= 1.-FC-FA
      X1=FA
      X2=FB
      WRITE(6,15)X1,X2,PC33
   15 FORMAT( 28HONEW MIXTURE RATIOS ARE. X1=,E10.3,2X,3HX2=,E10.3,
     12X,3HX3=,E10.3)
C     TEST IF PHYSICALLY POSSIBLE
      IF(X1.LT.0.)GO TO 80
      IF(X2.LT.0.)GO TO 80
      PC31=X1
      PC32=X2
      PNW=TAB(1,5,1)/144.
      TNW=TAB(1,6,1)/1.8
      GO TO 200
   50 CONTINUE
      WRITE(6,51)WMN
   51 FORMAT(5X,4HWMN=E10.3,38HNEW MW LT MIN.,ADJUST PRESSURE    DOWN)
      RATIO = PRPR(5,2)/PC(2)
      PNW= TAB(1,5,1)*RATIO/144.
      TNW =  TAB(1,6,1)/1.8
      IF(PNW.LT.0.)GO TO 100
      GO TO 200
   70 CONTINUE
```

```
      WRITE(6,71)WMN
   71 FORMAT(5X,4HWMN=E10.3,36HNEW MW GT MAX.,ADJUST PRESSURE    UP)
      RATIO = PRPR(5,2)/PC(2)
      PNW= TAB(1,5,1)*RATIO/144.
      TNW =  TAB(1,6,1)/1.8
      IF(PNW.GT.PMAX)GO TO 105
      GO TO 200
   80 CONTINUE
      WRITE(6,81)X1,X2
   81 FORMAT(5X,3HX1=,E10.3,5X,3HX2=,E10.3,5X,12HCHANGE GASES)
      GO TO 110
C     FLAGS SET IN THIS SECTION TO CHANGE GASES
  100 CONTINUE
      WRITE(6,101)
  101 FORMAT(13H0PLOW REACHED)
      KAZE=.TRUE.
      PNW=PCHAMI
      TNW=TCHAMI
      NOK=1
      GO TO 200
  105 CONTINUE
      WRITE(6,106)
  106 FORMAT(13H0P HI REACHED)
      KAZE=.TRUE.
      PNW=PCHAMI
      TNW=TCHAMI
      NOK=1
      GO TO 200
  110 CONTINUE
      PNW=PCHAMI
      TNW=TCHAMI
      NOK=1
      KAZE=.TRUE.
  200 RETURN
      END
$IBFTC WTM01
      SUBROUTINE WTMOL(SA,SB,SC)
      COMMON/CHANGE/PC11,PC21,PC22,PC31,PC32,PC33,PNW,TNW,DELM,DELMN,
```

```
      $DELREY
       COMMON/GASES/TAB(3,12,13),NMIX
       DIMENSION A(20,3),B(3),C(3)
C      LOAD QUANTITIES INTO ARRAYS
C      COMPUTE MOLECULAR WTS OF INDIVIDUAL GASES
       A(1,1)=PC31+PC32
       A(1,2)=0.
       A(1,3)=PC33
       A(2,1)=0.
       A(2,2)=PC31+PC32
       A(2,3)=PC33
       A(3,1)=PC31
       A(3,2)=PC32
       A(3,3)=PC33
       CALL GASINV(A,3,DET)
       B(1)= 1./TAB(2,7,1)
       B(2)= 1./TAB(3,7,1)
       B(3)= 1./TAB(1,7,1)
       CALL MATMPY(A,B,C,3,3,1)
       SA=1./C(1)
       SB=1./C(2)
       SC=1./C(3)
       RETURN
       END
```

```
$IBFTC MEA1     DECK
      SUBROUTINE MEAN(DEM,P)
      COMMON/AVE/EMM,EMWM,HM,HOM,GM,SLP1,SLP2
      COMMON/ENDS/TE(2),G(2),HOE(2),HE(2),EME(2)
      COMMON/PLUNMU/XC(5),PC(5),EMC(5),GMC(5),TC(5),QC(5),EMWC(5)
      COMMON/GASES/TAB(3,12,13),NMIX
      CALL ENDPT(P)
C     C
C     COMPUTE EXTRA PROPERTIES AT PLUME PT
      UGC=1545.
      RGC=UGC/EMWC(2)
      CP= GMC(2)*RGC/(GMC(2)-1.)
      H = CP*TC(2)
      HO= H+.5*QC(2)**2
C     TEST ON DIRECTION OF CHANGE
C     AND SET END POINT VALUES
      IF(DEM.GT.0.)GO TO 100
C     NEGATIVE MACH NO. AND THUS MW CHANGE
      G1=G(1)
      HO1=HOE(1)
      H1=HE(1)
      EMW1=TAB(2,7,1)
      SLP1=(H-H1)/(EMWC(2)-EMW1)
      SLP2=(GMC(2)-G1)/(EMWC(2)-EMW1)
      EMM=(EME(1)+EMC(2))/2.0
      GM=(GMC(2)+G1)/2.0
      EMWM=(EMW1+EMWC(2))/2.0
      HM= (H1+H)/2.0
      HOM=(HO+HO1)/2.0
      GO TO 200
  100 CONTINUE
      G1=G(2)
      HO1=HOE(2)
      H1=HE(2)
      EMW1= TAB(3,7,1)
      SLP1= (H-H1)/(EMWC(2)-EMW1)
      SLP2= (GMC(2)-G1)/(EMWC(2)-EMW1)
      EMM = (EME(1)+EMC(2))/2.0
```

```
      EMWM= (EMW1+EMWC(2))/2.0
      HM=(H1+H)/2.0
      HOM=(HO+HO1)/2.0
      GM= (GMC(2)+G1)/2.0
  200 CONTINUE
      IWRIT=1
      IF(IWRIT .EQ.0)GO TO 20
      WRITE(6,5)
    5 FORMAT(25HOMEAN PROPERTIES OF GASES)
      WRITE(6,10)
   10 FORMAT(10X,3HEMM,8X,4HEMWM,8X,2HHM,9X,3HHOM,8X,2HGM)
      WRITE(6,15)EMM,EMWM,HM,HOM,GM
   15 FORMAT(6X,5E10.3)
   20 CONTINUE
      RETURN
      END
```

```
$IBFTC ENDP1    DECK
       SUBROUTINE ENDPT(P)
       COMMON/ENDS/TE(2),G(2),HOE(2),HE(2),EME(2)
       COMMON/GASCON/GAMA,R,T0,P0,EM,RHO,T,WM,Q
       COMMON/ENTH/H
C      SUBROUTINE COMPUTES GAS PROPERTIES OF INDIVIDUAL SPECIE GASES
C      AT PRESSURE SPECIFIED
       P1=P
       DO 200 J=2,3
       L=J-1
       CALL TABLE(P1,J)
       TE(L)=T
       G(L)=GAMA
       HE(L)=H
       HOE(L)=H+.5*Q**2
       EME(L)=EM
       WRITE(6,10) P
   10  FORMAT(48H0END POINT PROPERTIES OF COMPOSITE AT PRESSURE= ,E10.3)
       WRITE(6,11)
   11  FORMAT(20X,3HGAS,6X,1HT,10X,1HH,10X,5HGAMMA,5X,1HM,10X,2HHO)
       WRITE(6,12)L,T,H,GAMA,EM,HOE(L)
   12  FORMAT(21X,I2,2X,6E10.3)
  200  CONTINUE
  100  RETURN
       END
$*
$ORIGIN         B
```

```
$IBFTC CECS1   DECK
      SUBROUTINE CEC (LSD,KACE)
C                                                                       10
C     TO LESSEN THE NO. OF CHANGES THAT MUST BE MADE, THE THERMODYNAMIC
C      DATA FOR THE TRANSPORT PROPERTIES WILL BE READ FROM TAPE 12, THE
C     OLD NASA/LEWIS DATA TAPE.
C      THE THERMODYNAMIC DATA FOR THE CEC PORTION WILL BE READ FROM TAPE
C      8, THE NEW DATA TAPE GENERATED BY MCDERMIT.
C      TO MAKE THESE COMPATABLE THE CEC IS MODIFIED TO READ THE GAS NAME
C      UNDER A 2A6 FORMAT.
C                                                                       30
      DOUBLE PRECISION G,X                                              40
      INTEGER DATA, OMIT, ENSERT, REAC, BLANK, THRM, END,SUB            50
      LOGICAL HP,SP,TP,IDEBUG,NEWR,IONS,MOLES,FROZ,EQL,PSIA,RKT         60
      LOGICAL SHOCK,MMHG,PASCAL,EV,IC,DETN,CPCVFR,CPCVEQ,SIUNIT,EUNITS  70
C                                                                       80
      INTEGER DATDUM
      DIMENSION DATDUM(5)
      COMMON/TAPE/IPROT
      COMMON/WRIT/IFLG1
      COMMON/GASES/TAB(3,12,13),NMIX
      COMMON/MOLFRC/ZFRAC(40),KFR
      DIMENSION OMIT(3,3),NCD(4),ENSERT(3,3),LH(2),LVP(2) ,LVM(2)       90
     1   ,WPSAVE(2)                                                    100
      COMMON/SUNUP/SUN(3,40,2)
      COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)       110
     1 ,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13)  120
     2   ,TOTN(13)                                                     130
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)   140
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)             150
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)  160
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2) 170
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)         180
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15) 190
     4 ,RHOP,RMW(15),TLN                                               200
      COMMON /DOUBLE/ G(20,21), X(20)                                   210
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM  220
     1   ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ 230
```

```
     2  ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                          240
      COMMON/PERF/PCP(26),VMOC(13),SPIM(13),VACI(13),SUBAR(13),SUPAR(13)    250
     1  ,CPRF(13),AEAT(13),CSTR,EQL,FROZ,SSO                               260
      COMMON/CASENO/LST
      COMMON/PNT/KPT(4)
C                                                                           270
      EQUIVALENCE (OMIT,ENLN),(ENSERT,EN(1,3)),(NLM,L)                      280
C                                                                           290
      DATA MIT/4HOMIT/,BLANK/1H /, PSIA/4HPSIA/,REAC/4HREAC/,IZ/2H00/       300
     1   ,INPUT/4HINPU/,IE/1HE/,INSERT/4HINSE/,THRM/4HTHER/,END/3HEND/      310
      DATA LH/4HH,CA,4HL/G /,LVP/2HV+,1H /,LVM/2HV-,1H /,NMLT/4HNAME/       320
      DATA (DATDUM(I),I=1,5)/6HREAC  ,6HNAME  ,6H      ,6H      ,
     16H      /
C                                                                           330
      NAMELIST/INPT2/KASE,P,T,EQRAT,OF,FPCT,FA,TP,HP,SP,RKT                 340
     1,PSIA,MMHG,SHOCK,IONS,EV,V,DETN,CPCVFR,CPCVEQ,IDEBUG                  350
     2,SIUNIT,EUNITS                                                        360
C                                                                           370
      LST=LSD
      KASE=KACE
      TLOW = 0.                                                             380
      NEWR = .FALSE.                                                        390
C                                                                           400
    1 WRITE(6,400)                                                          410
  400 FORMAT(1H1)                                                           420
      DATA(1)=DATDUM(1)
  203 CONTINUE
  204 FORMAT(5(3A4,3X))                                                     440
      WRITE (6,2045)(DATA(I),I=1,15)                                        450
 2045 FORMAT(1X,5(3A4,3X))                                                  460
      IF(DATA(1).EQ.REAC)  GO TO 11                                         480
      IF(DATA(1).EQ.INPUT.OR.DATA(1).EQ.NMLT)  GO TO 210                    510
      IF(DATA(1).EQ.BLANK) GO TO 203                                        520
 1023 WRITE(6,1024)                                                         530
 1024 FORMAT(40H0ERROR IN ABOVE CARD.  IGNORE CONTENTS.  )                  540
      GO TO 203                                                             550
   11 CONTINUE
      NOMIT=0
```

```
      NSERT = 0                                                          570
      MOLES = .FALSE.                                                    580
      CALL REACT                                                         590
      DATA(1)=DATDUM(2)
      WPSAVE(1) = WP(1)                                                  600
      WPSAVE(2) = WP(2)                                                  610
      IF(L.EQ.0)  WRITE(6,52)                                            620
   52 FORMAT(24H0ERROR IN REACTANT CARDS)                                630
      GO TO 203                                                          640
C                                                                        650
C                                                                        890
C                                                                       1120
C     BEGIN NAMELIST INPT2                                              1130
C                                                                       1140
  210 DO 300 I=1,26                                                     1150
      V(I) = 0.                                                         1190
  300 CONTINUE                                                          1200
      DO 307 I=2,26
      P(I)=0.0
  307 T(I)=0.0
C     SET PRESSURE RATIO ARRAY
      PCP(1)=1.0
      PCP(2)=25.0
      PCP(3)=300.0
      PCP(4)=1000.0
      PCP(5)=2000.0
      PCP(6)=3000.0
      PCP(7)=4000.0
      PCP(8)=5000.0
      PCP(9)=7000.0
      PCP(10)=10000.
      PCP(11)=30000.
      PCP(12)=60000.
      PCP(13)=100000.
C
      DO 308 I=14,26
  308 PCP(I)=0.0
      V1 = 0.                                                           1210
```

```
      V2 = 0.                                                          1220
      RHOP = 0.                                                        1230
      RKT=.TRUE.
      HP=.FALSE.                                                       1260
      SP=.FALSE.                                                       1270
      TP=.TRUE.
      IF(IPROT.EQ.1)TP=.FALSE.
      CPCVFR = .FALSE.                                                 1290
      CPCVEQ = .FALSE.                                                 1300
      SHOCK = .FALSE.                                                  1310
      DETN = .FALSE.                                                   1320
      EV = .FALSE.                                                     1330
      PASCAL = .FALSE.                                                 1340
      MMHG   = .FALSE.                                                 1350
      PSIA=.TRUE.
      R = 1.987165                                                     1370
      RR = 4184.*R                                                     1380
      SIUNIT = .FALSE.                                                 1390
      EUNITS = .FALSE.                                                 1400
      IONS = .FALSE.                                                   1410
      IDEBUG=.FALSE.
      IF(IFLG1.EQ.1)IDEBUG=.TRUE.
      FA = 0.                                                          1430
      OF = 0.                                                          1440
      EQRAT= 0.                                                        1450
      FPCT= 0.                                                         1460
      EQL = .TRUE.                                                     1470
      DO 305 I=1,26                                                    1490
      IF(P(I ).EQ.0.) GO TO 322                                        1500
      NP = I                                                           1510
      IF (MMHG) P(NP) = P(NP)/760.                                     1520
      IF (PASCAL) P(NP) = P(NP)/101325.                                1530
      IF(PSIA          )  P(NP)=P(NP)/14.696006                        1540
  305 CONTINUE                                                         1550
  322 IF (FA.NE.0.) OF = 1./FA                                         1560
      IF(EQRAT.EQ.0.) GO TO 725                                        1570
      OF= (-EQRAT*VMIN(2)-VPLS(2))/(VPLS(1)+EQRAT*VMIN(1))             1580
      GO TO 727                                                        1590
```

```
 725 IF(OF.NE.0.) GO TO 727                                                    1600
     IF(FPCT.EQ.0.) GO TO 9051                                                 1610
     OF= (100.-FPCT)/FPCT                                                      1620
     GO TO 727                                                                 1630
9051 WRITE(6,724)                                                              1640
 724 FORMAT(48HONO INPT2 VALUE GIVEN FOR OF, EQRAT, FA, OR FPCT   )            1650
     IF(WP(2).NE.0.) OF=WPSAVE(1)/WPSAVE(2)                                    1660
 727 WP(1) = OF                                                                1670
     WP(2) = 1.                                                                1680
     SUM = WP(1)+WP(2)                                                         1690
     FPCT = 100.*WP(2)/SUM                                                     1700
     IF (EQRAT.NE.0.)  GO TO 746                                               1710
     V2 = (WP(1)*VMIN(1)+WP(2)*VMIN(2))/SUM                                    1720
     V1 = (WP(1)*VPLS(1)+WP(2)*VPLS(2))/SUM                                    1730
     IF(V2.NE.0.)  EQRAT=ABS(V1/V2)                                            1740
 746 DO 747 I=1,L                                                              1750
     BO(I) = (WP(1)*BOP(I,1)+WP(2)*BOP(I,2))/SUM                               1760
 747 CONTINUE                                                                  1770
     IF (EQRAT.EQ.1.)  EQRAT= 1.000005                                         1780
     IF(.NOT.IONS.OR.LLMT(L).EQ.IE)  GO TO 748                                 1790
     L = L+1                                                                   1800
     LLMT(L) = IE                                                              1810
     BO(L) = 0.                                                                1820
 748 HSUBO = (WP(1)*HPP(1)+WP(2)*HPP(2))/SUM                                   1830
     IF(NEWR) CALL SEARCH                                                      1840
     DO 755 N=1,NREAC                                                          1850
     IF(NAME(N,5).NE.IZ)  GO TO 755                                            1860
     TT = RTEMP(N)                                                             1870
     CALL HCALC                                                                1880
     GO TO 760                                                                 1890
 755 CONTINUE                                                                  1900
     IF(IFLG1.EQ.0)GO TO 291
 760 WRITE(6,INPT2)                                                            1910
     WRITE (6,770)                                                             1920
 770 FORMAT (1H0,17X,4HFUEL ,13X,7HOXIDANT  ,12X,7HMIXTURE   //)               1930
 780 FORMAT (1H 2A4,3E18.8/)                                                   1940
     WRITE (6,780) LH,HPP(2),HPP(1),HSUBO,LVP,VPLS(2),VPLS(1),V1,              1950
    1LVM,VMIN(2),VMIN(1),VP                                                    1960
```

```
291 CONTINUE
    HSUB0 = HSUB0/R                                                    1970
    WRITE (6,785)                                                      1980
785 FORMAT (8H ATOMS/G  )                                              1990
    WRITE(6,780)(LLMT(I),BLANK,BOP(I,2),BOP(I,1),BO(I),I=1,L)          2000
    RHOP = WP(2)*RHO(1)+WP(1)*RHO(2)                                   2010
    IF(RHOP.NE.0.)  RHOP = (WP(1)+WP(2))*RHO(1)*RHO(2)/RHOP            2020
    IQ1= L+1                                                           2030
    IF(NC.EQ.0)  GO TO 790                                             2040
    DO 302 J=1,NS                                                      2050
    IF(IUSE(J).EQ.0) GO TO 302                                         2060
    IF(IUSE(J).GT.0) IUSE(J)= -IUSE(J)                                 2070
    IF(NSERT.EQ.0) GO TO 302                                           2080
    DO 301 I=1,NSERT                                                   2090
    IF(SUB(J,1).NE.ENSERT(1,I)) GO TO 301                              2100
    IF(SUB(J,2).NE.ENSERT(2,I)) GO TO 301                              2110
    IF(SUB(J,3).NE.ENSERT(3,I)) GO TO 301                              2120
    ENSERT(1,I) =0.                                                    2130
    IQ1= IQ1+1                                                         2140
    IUSE(J)= -IUSE(J)                                                  2150
301 CONTINUE                                                           2160
302 CONTINUE                                                           2170
    NSERT = 0                                                          2180
790 ITN= 35                                                            2190
    IC = .FALSE.                                                       2200
    PP = NS                                                            2210
    NPT = 1                                                            2220
    ENN = .1                                                           2230
    SUMN = ENN                                                         2240
    XI = NS - NC                                                       2250
    XI = FNN/XI                                                        2260
    XLN = ALOG(XI)                                                     2270
    DO 432 J=1,NS                                                      2280
    IF(IUSE(J).EQ.-10000)  IUSE(J)=0                                   2290
    EN(J,1) = 0.                                                       2300
    ENLN(J)=0.                                                         2310
    IF (IUSE(J).NE.0)  GO TO 432                                       2320
    EN(J,1) = XI                                                       2330
```

```
      ENLN(J) = XLN                                                    2340
  432 CONTINUE                                                         2350
      JSOL = 0                                                         2360
      JLIQ = 0                                                         2370
      IF(RKT) CALL ROCKET                                              2390
      KPT(LST)=NPT
      RETURN
      END                                                              2430
```

```
$IBFTC CECS18  DECK
      BLOCK DATA                                                                10
C                                                                               20
      DIMENSION ATEM(3,50)                                                      30
C                                                                               40
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)          50
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2)        60
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)                 70
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15)        80
     4 ,RHOP,RMW(15),TLN                                                        90
C                                                                              130
      EQUIVALENCE (ATOM(1,52),ATEM)                                            140
C                                                                              150
C  ATOMIC SYMBOLS, WEIGHTS, AND VALENCES                                       160
C                                                                              170
      DATA ATOM/                                                               180
     A   2HH , 1.00797, 1.,   2HHE, 4.0026, 0.,   2HLI,  6.939  , 1.,        190
     B   2HBE,  9.0122 , 2.,  2HB , 10.811 , 3.,   2HC , 12.01115, 4.,        200
     C   2HN , 14.0067 , 0.,  2HO , 15.9994,-2.,  2HF , 18.9984 ,-1.,        210
     D   2HNE, 20.183  , 0.,  2HNA, 22.9898, 1.,  2HMG, 24.312  , 2.,        220
     E   2HAL, 26.9815 , 3.,  2HSI, 28.086 , 4.,  2HP , 30.9738 , 5.,        230
     F   2HS , 32.064  , 4.,  2HCL, 35.453 ,-1.,  2HAR, 39.948  , 0.,        240
     G   2HK , 39.102  , 1.,  2HCA, 40.080 , 2.,  2HSC, 44.956  , 3.,        250
     H   2HTI, 47.900  , 4.,  2HV , 50.942 , 5.,  2HCR, 51.996  , 3.,        260
     I   2HMN, 54.9380 , 2.,  2HFE, 55.847 , 3.,  2HCO, 58.9332 , 2.,        270
     J   2HNI, 58.710  , 2.,  2HCU, 63.540 , 2.,  2HZN, 65.370  , 2.,        280
     K   2HGA, 69.720  , 3.,  2HGE, 72.590 , 4.,  2HAS, 74.9216 , 3.,        290
     L   2HSE, 78.960  , 4.,  2HBR, 79.909 ,-1.,  2HKR, 83.800  , 0.,        300
     M   2HRB, 85.47   , 1.,  2HSR, 87.620 , 2.,  2HY , 88.905  , 3.,        310
     N   2HZR, 91.220  , 4.,  2HNB, 92.906 , 5.,  2HMO, 95.94   , 6.,        320
     O   2HTC, 99.000  , 7.,  2HRU,101.070 , 3.,  2HRH,102.905  , 3.,        330
     P   2HPD,106.400  , 2.,  2HAG,107.870 , 1.,  2HCD,112.400  , 2.,        340
     Q   2HIN,114.820  , 3.,  2HSN,118.690 , 4.,  2HSB,121.750  , 3. /       350
      DATA ATEM/                                                               360
     R   2HTE,127.600  , 4.,  2HI ,126.9044,-1.,  2HXE,131.300  , 0.,        370
     S   2HCS,132.905  , 1.,  2HBA,137.340 , 2.,  2HLA,138.910  , 3.,        380
     T   2HCE,140.120  , 3.,  2HPR,140.907 , 3.,  2HND,144.240  , 3.,        390
     U   2HPM,145.000  , 3.,  2HSM,150.350 , 3.,  2HEU,151.960  , 3.,        400
```

```
V    2HGD,157.250  , 3.,   2HTB,158.924 , 3.,   2HDY,162.500  , 3.,    410
W    2HHO,164.930  , 3.,   2HER,167.260 , 3.,   2HTM,168.934  , 3.,    420
X    2HYB,173.040  , 3.,   2HLU,174.997 , 3.,   2HHF,178.490  , 4.,    430
Y    2HTA,180.948  , 5.,   2HW ,183.850 , 6.,   2HRE,186.200  , 7.,    440
Z    2HOS,190.200  , 4.,   2HIR,192.200 , 4.,   2HPT,195.090  , 4.,    450
A    2HAU,196.967  , 3.,   2HHG,200.590 , 2.,   2HTL,204.370  , 1.,    460
B    2HPB,207.190  , 2.,   2HBI,208.980 , 3.,   2HPO,210.000  , 2.,    470
C    2HAT,210.000  , 0.,   2HRN,222.000 , 0.,   2HFR,223.000  , 1.,    480
D    2HRA,226.000  , 2.,   2HAC,227.000 , 3.,   2HTH,232.038  , 4.,    490
E    2HPA,231.000  , 5.,   2HU ,238.030 , 6.,   2HNP,237.000  , 5.,    500
F    2HPU,242.000  , 4.,   2HAM,243.000 , 3.,   2HCM,247.000  , 3.,    510
G    2HBK,249.000  , 3.,   2HCF,251.000 , 3.,   2HES,254.000  , 0.,    520
H    2HFM,253.000  , 0.,   2HMV,256.000 , 0./                          530
 END                                                                   740
$*
```

```
$IBFTC CECS13  DECK
C                                                                       10
      SUBROUTINE ROCKET                                                 20
C                                                                       30
C     ROCKET PERFORMANCE                                                40
C     EITHER HPSP OR TPSP IS TRUE                                       50
C                                                                       60
      LOGICAL HP,SP,TP,IDEBUG,NEWR ,IONS,MOLES,FROZ,EQL,LOGV,HPSP,TPSP  70
C                                                                       80
      DIMENSION AA(2),BB(2),CC(2)                                       90
C                                                                      100
      COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)      110
     1 ,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13) 120
     2,TOTN(13)                                                        130
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)  140
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)            150
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)  160
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2) 170
     2 ,HPP(2),RH0(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)         180
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15) 190
     4 ,RHOP,RMW(15),TLN                                               200
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM  210
     1   ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ 220
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                      230
      COMMON/PERF/PCP(26),VMOC(13),SPIM(13),VACI(13),SUBAR(13),SUPAR(13)
     1,CPRF(13),AEAT(13),CSTR,EQL,FROZ,SSO
      COMMON/CASENO/LST
      COMMON/TAPE/IPROT
C                                                                      260
C                                                                      280
      NAMELIST/RKTINP/EQL,FROZ,SUBAR,SUPAR,PCP                         270
      ITH = 0                                                          290
  210 DO 300 I=1,26                                                    300
      SUBAR(I) = 0.                                                    320
  300 CONTINUE                                                         330
      HPSP = .TRUE.                                                    340
      HP = .TRUE.                                                      350
      TPSP = .FALSE.                                                   360
```

```
      FOL=.FALSE.                                                       380
      FROZ = .TRUE.
       IF(IPROT.EQ.1)T(1)=0.
      IF (T(1).EQ.0.)  GO TO 302                                        400
      TPSP = .TRUE.                                                     410
      TP = .TRUE.                                                       420
      HPSP = .FALSE.                                                    430
      GO TO 303                                                         440
  302 T(1) = 3800.                                                      450
  303 IF(PCP(1).NE.0.)  GO TO 308                                       460
      DO 305  I=1,NP                                                    470
      K = NP-I+2                                                        480
      P(K) = P(K-1)                                                     490
  305 CONTINUE                                                          500
      GO TO 311                                                         510
  308 NP= 2                                                             520
      DO 310 I=1,24                                                     530
      IF (I.GT.2) GO TO 309                                             540
      IF ((PCP(I).EQ.0.).OR.PCP(I).EQ.1.) GO TO 310                     550
  309 IF (PCP(I).EQ.0.) GO TO 311                                       560
      NP = NP + 1                                                       570
      P(NP) = P(1)/PCP(I)                                               580
  310 CONTINUE                                                          590
  311 NSUB=0                                                            600
      NSUP = 0                                                          610
      DO 320  I=1,13                                                    620
      IF(SUBAR(I).NE.0.)NSUB=NSUB+1                                     630
      IF(SUPAR(I).NE.0.)NSUP=NSUP+1                                     640
  320 CONTINUE                                                          650
      IF(IFLG1.EQ.0)GO TO 294
      WRITE (6,RKTINP)                                                  660
  294 CONTINUE
      ITROT= 3                                                          680
      SSO = 0.                                                          670
      TT = T(1)                                                         690
C                                                                       700
C     SET ASSIGNED P                                                    710
C                                                                       720
```

```
      DO 902 IP = 1,NP                                                  730
      PP = P(IP)                                                        740
      CALL EQLBRM                                                       750
C
      IF(IFLG1.EQ.0)GO TO 291
      WRITE(6,5200)TT,NPT
 5200 FORMAT(11HOTT IN RKT=E10.3,2X,4HNPT=I5)
  291 CONTINUE
C
      T(NPT) = TT                                                       760
      IF(TT.NE.0.)  GO TO 333                                           770
      IF(NPT.EQ.0)  GO TO 1000                                          780
      GO TO 900                                                         790
  333 PCP(NPT) = P(1)/PP                                                800
      IF(IP.GT.1)  GO TO 195                                            810
C                                                                       820
C     COMBUSTION CHAMBER                                                830
C                                                                       840
      TP = .FALSE.                                                      850
      HP = .FALSE.                                                      860
      SP = .TRUE.                                                       870
      S0 = SSUM(1)                                                      880
      PCP(2)=((GAMMAS(1)+1.)/2.)**(GAMMAS(1)/(GAMMAS(1)-1.))            890
      P(2) = P(1)/PCP(2)                                                900
      TT = 2.*TT/(GAMMAS(1)+1.)                                         910
      GO TO 900                                                         920
  195 IF(IP.GT.2) GO TO 900                                             930
C                                                                       940
C     THROAT                                                            950
C                                                                       960
  190 IF(ITH.NE.2)  GO TO 191                                           970
      ITH = 0                                                           980
      GAMMAS(2) = 0.                                                    990
      GO TO 900                                                        1000
  191 DH = HSUM(1)-HSUM(2)                                             1010
      DHSTAR = DH-GAMMAS(2)*TT*ENN/2.                                  1020
      IF (IDEBUG) WRITE(6,923)DHSTAR,HSUM(1),HSUM(2),PCP(2)            1030
  923 FORMAT(4E25.8)                                                   1040
```

```
      DH = DHSTAR/DH                                                    1050
      IF(DH.LT.0.)  DH=-DH                                              1060
      IF(DH.LE.0.4E-4.OR.ITROT.EQ.0)  GO TO 900                         1070
      IF(JSOL.NE.0) ITH =1                                              1080
      IF (JSOL.EQ.0.AND.ITH.EQ.1) ITH=2                                 1090
      IF(ITH.EQ.0) GO TO 192                                            1100
C                                                                       1110
C     SPECIAL THROAT INTERPOLATION IF ITH = 2                           1120
C                                                                       1130
      DLNI = .5*TT*ENN/(HSUM(1)-HSUM(2))                                1140
      AA(ITH)=.5*DLNI*(2.*DLNI+(GAMMAS(2)-1.)/GAMMAS(2))                1150
      XX = ALOG(PCP(2))                                                 1160
      BB(ITH) = 1./GAMMAS(2)-DLNI-2.*XX*AA(ITH)                         1170
      CC(ITH) = ENN*TT/(PP*(HSUM(1)-HSUM(2))**.5)                       1180
      CC(ITH) = ALOG(CC(ITH))-XX*(BB(ITH)+AA(ITH)*XX)                   1190
      IF(ITH.EQ.1)  GO TO 192                                           1200
      BB(1)=BB(1)-BB(2)                                                 1210
      AA(1)=AA(1)-AA(2)                                                 1220
      PCP(2)=(-BB(1)+(BB(1)*BB(1)-4.*AA(1)*(CC(1)-CC(2)))**.5)/(2.*AA(1)1240
      PCP(2)=EXP(PCP(2))                                                1250
      GO TO 193                                                         1260
  192 PCP(2)= PCP(2)/(1.+2.*DHSTAR/(ENN*TT *(GAMMAS(2)+1.)))            1270
  193 P(2) = P(1) / PCP(2)                                              1280
      PP = P(2)                                                         1290
      ITROT = ITROT-1                                                   1300
      CALL EQLBRM                                                       1310
      IF(TT.EQ.0.) GO TO 1000                                           1320
      GO TO 190                                                         1330
C                                                                       1340
  900 K = 0                                                             1350
      IF (.NOT.EQL .AND. FROZ) GO TO 990                                1360
      IF(IP.EQ.NP.OR.TT.EQ.0.)  GO TO 860                               1370
      K = NPT                                                           1380
      IF(NPT.NE.13)  GO TO 870                                          1390
  860 CALL RKTOUT                                                       1400
      IF(K.EQ.0) GO TO 990                                              1420
      WRITE(6,865)                                                      1430
```

```
  865 FORMAT(1H1)                                                        1440
      NPT = 2                                                            1450
  870 NPT = NPT + 1                                                      1460
C                                                                        1470
C    SAVE COMPOSITIONS FOR ESTIMATES OF NEXT POINT                       1480
C                                                                        1490
      DO 880 I = 1,NS                                                    1500
      EN(I,NPT) = EN(I,K)                                                1510
  880 CONTINUE                                                           1520
  902 CONTINUE                                                           1530
  990 IF (FROZ) CALL FROZEN                                              1540
 1000 RETURN                                                             1550
      END                                                                1560
```

```
$ORIGIN         E
$IBFTC CECS4    DECK
C                                                                       10
      SUBROUTINE EQLBRM                                                 20
C  ROUTINE TO CALCULATE EQUILIBRIUM COMPOSITION AND PROPERTIES          30
C                                                                       40
      DOUBLE PRECISION X,G                                              50
      LOGICAL HP,SP,TP,IDEBUG,CONVG,IONS,MOLES,FROZ,EQL,LOGV,HPSP,TPSP  60
      LOGICAL ISING,IC                                                  70
C                                                                       80
      DIMENSION PROW(18)                                                90
C                                                                       100
      COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)       110
     1 ,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13)  120
     2,TOTN(13)                                                         130
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)   140
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)             150
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)  160
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2) 170
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)         180
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15) 190
     4 ,RHOP,RMW(15),TLN                                                200
      COMMON /DOUBLE/ G(20,21), X(20)                                   210
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM  220
     1  ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ  230
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                       240
      COMMON/PERF/PCP(26),VMOC(13),SPIM(13),VACI(13),SUBAR(13),SUPAR(13) 250
     1 ,CPRF(13),AEAT(13),CSTR,EQL,FROZ,SS0                             260
C                                                                       270
      COMMON/CASENO/LST                                                 280
      EQUIVALENCE (NLM,L)                                               290
C                                                                       300
      DATA ITER/4HITER/,IE/1HE/,SMALNO/1.E-6/,SMNOL/-13.815511/         310
C                                                                       320
      SIZE= 18.5                                                        330
      ISING = .FALSE.                                                   340
      ENNL = ALOG(ENN)                                                  350
      LOGV = .FALSE.
```

```
      PPLN = ALOG(PP)                                                   360
      TLN = ALOG(TT)                                                    370
      CONVG = .FALSE.                                                   380
      ITNUMB = ITN                                                      390
      IF(IC)  GO TO 966                                                 400
      IF (.NOT.IONS.OR.IE.EQ.LLMT(L)) GO TO 33                          410
      L = L+1                                                           420
      IQ1 = IQ1+1                                                       430
      DO 499 J = 1,NS                                                   440
      IF (A(L,J) .EQ.0.) GO TO 499                                      450
      EN(J,NPT) = SMALNO                                                460
      ENLN(J) = SMNOL                                                   470
      IUSF(J) = 0                                                       480
  499 CONTINUE                                                          490
   33 IF(NPT.EQ.1) WRITE(6,244)(LLMT(I),I=1,L),ITER                     500
  244 FORMAT (4HOPT ,14(5X,A4))                                         510
   43 TM = ALOG(PP/ENN)                                                 520
      JS1 = 1                                                           530
      IF(.NOT.TP) CALL CPHS                                             540
      IF(TP.AND.(CONVG.OR.ITNUMB.EQ.ITN)) CALL CPHS                     550
      IF(IC)  GO TO 171                                                 560
      IF (.NOT.CONVG.OR.JSOL.EQ.0) GO TO 62                             570
      ENSOL = EN(JSOL,NPT)                                              580
      EN(JSOL,NPT) = EN(JSOL,NPT)+EN(JLIQ,NPT)                          590
      IUSE(JLIQ) = -IUSE(JLIQ)                                          600
      IQ1 = IQ1-1                                                       610
      DLVTP(NPT) = 0.                                                   620
      CPR(NPT) = 0.                                                     630
      GAMMAS(NPT) = 0.                                                  640
      LOGV = .TRUE.                                                     650
   62 CALL MATRIX                                                       660
      NUMB = ITN-ITNUMB+1                                               670
      IF(.NOT.CONVG)     GO TO 67                                       680
      IF (LOGV.AND.JSOL.EQ.0) GO TO 63                                  690
      DO 182  I=1,L                                                     700
      PROW(I) = G(IQ1,I)                                                710
  182 CONTINUE                                                          720
      IF (.NOT.LOGV) GO TO 67                                           730
```

```
C                                                                       740
C     LOGV = .TRUE.-- SET UP MATRIX TO SOLVE FOR DLVPT                  750
C                                                                       760
   63 G(IQ1,IQ2) = ENN                                                  770
      IQ = IQ1 - 1                                                     780
      DO 777 I = 1,IQ                                                  790
      G(I,IQ2) = G(I,IQ1)                                              800
  777 CONTINUE                                                         810
   67 IF (.NOT.IDEBUG) GO TO 72                                        820
      WRITE(6,772) NUMB                                                830
  772 FORMAT (11HOITERATION  ,I3,6X,7HMATRIX //)                       840
      DO 911 I=1,IMAT                                                  850
  911 WRITE (6,73) (G(I,K),K=1,KMAT)                                   860
   72 IF(CONVG)  IMAT=IMAT-1                                           870
      ITST = IMAT                                                      880
      CALL MGAUSD                                                      890
      IF(ITST.NE.IMAT)  GO TO 774                                      900
      IF(.NOT.IDEBUG.OR.CONVG)  GO TO 773                              910
      WRITE (6,373)(LLMT(I),I=1,L)                                     920
  373 FORMAT (7HOPI     ,9(A4,10X))                                    930
      WRITE (6,73)(X(I),I=1,IMAT)                                      940
   73 FORMAT (9E14.6)                                                  950
  773 IF(.NOT.CONVG)  GO TO 85                                         960
      IF(LOGV)  GO TO 171                                              970
  174 SUM = 0.                                                         980
      DO 175 J=1,L                                                     990
      SUM = SUM+PROW(J)*X(J)                                          1000
  175 CONTINUE                                                        1010
      DLVTP(NPT) = 1.+G(IQ2,IQ1)/ENN-SUM/ENN  - X(IQ1)                1020
      CPR(NPT) = G(IQ2,IQ2)                                           1030
      DO 176 J=1,IQ1                                                  1040
      CPR(NPT) = CPR(NPT)-G(IQ2,J)*X(J)                               1050
  176 CONTINUE                                                        1060
      LOGV = .TRUE.                                                   1070
      GO TO 62                                                        1080
C                                                                     1090
C  SINGULAR MATRIX                                                    1100
C                                                                     1110
```

```
774 IF(.NOT.CONVG)  GO TO 775                                          1120
    WRITE(6,172)                                                      1130
172 FORMAT(28H0DERIVATIVE MATRIX SINGULAR )                           1140
    IC = .TRUE.                                                       1150
    GO TO 171                                                         1160
775 IF (.NOT.HP.OR.NPT.NE.1.OR.NC.EQ.0.OR.TT.GT.100.)  GO TO 871      1170
    WRITE(6,874)                                                      1180
874 FORMAT(96H0LOW TEMPERATURE IMPLIES CONDENSED SPECIES SHOULD HAVE  1190
   1BEEN INCLUDED ON AN INSERT CARD, RESTART )                        1200
    GO TO 873                                                         1210
871 WRITE (6,74)                                                      1220
 74 FORMAT(16H0SINGULAR MATRIX)                                       1230
    IF(IC)  GO TO 873                                                 1240
    IF (ISING) GO TO 997                                              1250
    NTZERO = 0                                                        1260
966 DO 970 JJ = 1, NS                                                 1270
    IF(IUSE(JJ)) 970,968,967                                          1280
967 IF(EN(JJ,NPT).EQ.0.)  GO TO 873                                   1290
    GO TO 969                                                         1300
968 IF(EN(JJ,NPT).NE.0.)  GO TO 969                                   1310
    EN(JJ,NPT) = SMALNO                                               1320
    ENLN(JJ) = SMNOL                                                  1330
    GO TO 970                                                         1340
969 NTZERO = NTZERO+1                                                 1350
970 CONTINUE                                                          1360
    IF(.NOT.IC)  GO TO 971                                            1370
    IC = .FALSE.                                                      1380
    GO TO 43                                                          1390
971 ISING = .TRUE.                                                    1400
    WRITE (6,776)                                                     1410
776 FORMAT (8H0RESTART)                                               1420
    GO TO 43                                                          1430
997 IF(NTZERO.NE.(L-1))  GO TO 873                                    1440
    IF(EQRAT.GT.1.00001.OR.EQRAT.LT.0.99999) GO TO 873                1450
    ENN=0.                                                            1460
    NEN = 0                                                           1470
    DO 83  I=1,L                                                      1480
    JEN=0                                                             1490
```

```
      DO 80  J=1,NS                                                    1500
      IF(EN(J,NPT).EQ.0.)  GO TO 80                                    1510
      IF(A(I,J).EQ.0.)  GO TO 80                                       1520
      IF(JEN.NE.0)  GO TO 83                                           1530
      JEN = J                                                          1540
   80 CONTINUE                                                         1550
      NEN = NEN+1                                                      1560
      EN(JEN,NPT) = B0(I)/A(I,JEN)                                     1570
   83 CONTINUE                                                         1580
      IF(NEN.LT.NTZERO)  GO TO 873                                     1590
      CONVG = .TRUE.                                                   1600
      IC = .TRUE.                                                      1610
      HSUM(NPT) = 0.                                                   1620
      DO 84  J=1,NS                                                    1630
      IF(EN(J,NPT).EQ.0.)  GO TO 84                                    1640
      ENN = EN(J,NPT)+ENN                                              1650
      TEM = EN(J,NPT)                                                  1660
      ENLN(J) = ALOG(TEM)                                              1670
      HSUM(NPT) = HSUM(NPT) + EN(J,NPT)*H0(J)                          1680
   84 CONTINUE                                                         1690
      TM = ALOG(PP/ENN)                                                1700
      GO TO 43                                                         1710
   85 ITNUMB= ITNUMB-1                                                 1720
C                                                                      1730
C     OBTAIN CORRECTIONS TO THE ESTIMATES                              1740
C                                                                      1750
      KK = L + 1                                                       1760
      DLNT= X(IQ2)                                                     1770
      IF (TP) DLNT=0.                                                  1780
      DO 101 J=1,NS                                                    1790
      IF (IUSE(J)) 101,98,100                                          1800
   98 DELN(J) = H0(J)*DLNT-H0(J)+S(J)-ENLN(J)-TM+X(IQ1)                1810
      DO 99 K=1,L                                                      1820
      DELN(J)= DELN(J)+A(K,J)*X(K)                                     1830
   99 CONTINUE                                                         1840
      GO TO 101                                                        1850
  100 DELN(J) = X(KK)                                                  1860
      KK = KK + 1                                                      1870
```

```
101  CONTINUE                                                          1880
     AMBDA= 1.                                                         1890
     AMBDA1= 1.                                                        1900
     SUM = X(IQ1)                                                      1910
     IF(SUM.LT.0.)  SUM=-SUM                                           1920
     IF(DLNT.GT.SUM)  SUM=DLNT                                         1930
     IF(-DLNT.GT.SUM)  SUM=-DLNT                                       1940
     DO 917 J=1,NS                                                     1950
     IF (IUSE(J).NE.0) GO TO 917                                       1960
     IF((EN(J,NPT).GT.0.).AND.DELN(J).GT.SUM) SUM = DELN(J)            1970
     IF((EN(J,NPT).NE.0.) .OR. DELN(J).LE.0.) GO TO 917                1980
     SUM1 = (-9.212-ENLN(J)+ENNL)/(DELN(J)-X(IQ1))                     1990
     IF(SUM1.LT.0.)  SUM1=-SUM1                                        2000
     IF (SUM1.LT.AMBDA1) AMBDA1 = SUM1                                 2010
917  CONTINUE                                                          2020
     IF(SUM.GT.2.)AMBDA=2./SUM                                         2030
     IF (AMBDA1.LT.AMBDA) AMBDA = AMBDA1                               2040
     IF (.NOT.IDEBUG) GO TO 111                                        2050
     WRITE(6,923) TT,ENN,ENNL,PP,PPLN,AMBDA                            2060
923  FORMAT (3H0T=,E15.8,6H  ENN=,E15.8,7H  ENNL=E15.8,5H  PP=,E15.8,  2070
    1 7H  PPLN=E15.8,8H  AMBDA=E15.8 )                                 2080
     WRITE (6,924)                                                     2090
924  FORMAT(1H0,18X,2HNI,12X,5HLN NI,8X,9HDEL LN NI,10X,4HH/RT,9X,4HS0/ 2100
    1R,12X,6H-G0/RT,9X,5H-G/RT  )                                      2110
     DO 926 J=1,NS                                                     2120
     FNEG1 = S(J)-H0(J)                                                2130
     FNEG2 = FNEG1                                                     2140
     IF(IUSE(J).EQ.0)  FNEG2=FNEG2-ENLN(J)-TM                          2150
     WRITE (6,925) SUB(J,1),SUB(J,2),                                  2160
    1SUB(J,3),EN(J,NPT),ENLN(J),DELN(J),H0(J),S(J),FNEG1,FNEG2         2170
925  FORMAT (1X,3A4,7E15.6)                                            2180
926  CONTINUE                                                          2190
     WRITE (6,110)                                                     2200
110  FORMAT(1H0)                                                       2210
C                                                                      2220
C    APPLY CORRECTIONS TO ESTIMATES                                    2230
C                                                                      2240
111  SUM = 0.                                                          2250
```

```
      DO 113 J=1,NS                                                    2260
      IF (IUSE(J)) 113,112,114                                         2270
  112 ENLN(J)=ENLN(J)+AMBDA*DELN(J)                                    2280
      EN(J,NPT) = 0.                                                   2290
      IF((ENLN(J)-ENNL+SIZE).LE.0.)  GO TO 113                         2300
      EN(J,NPT) = EXP(ENLN(J))                                         2310
      SUM = SUM+EN(J,NPT)                                              2320
      GO TO 113                                                        2330
  114 EN(J,NPT) = EN(J,NPT) + AMBDA * DELN(J)                          2340
  113 CONTINUE                                                         2350
      SUMN = SUM                                                       2360
      IF (TP) GO TO 115                                                2370
      TLN= TLN+AMBDA*DLNT                                              2380
      TT      = EXP(TLN)                                               2390
  115 ENNL = ENNL+AMBDA*X(IQ1)                                         2400
      ENN = EXP(ENNL)                                                  2410
      IF (LLMT(L).NE.IE) GO TO 116                                     2420
C                                                                      2430
C     CHECK ON REMOVING IONS                                           2440
C                                                                      2450
      DO 1116 J = 1,NS                                                 2460
      IF (A(L,J).EQ.0.) GO TO 1116                                     2470
      IF (EN(J,NPT).GT.0.) GO TO 116                                   2480
 1116 CONTINUE                                                         2490
      DO 1118  J=1,NS                                                  2500
      IF(A(L,J).NE.0.) IUSE(J) = -10000                                2510
 1118 CONTINUE                                                         2520
      L = L-1                                                          2530
      IQ1 = IQ1-1                                                      2540
      GO TO 43                                                         2550
C                                                                      2560
C     TEST FOR CONVERGENCE                                             2570
C                                                                      2580
  116 IF (ITNUMB.EQ.0) GO TO 13                                        2590
      IF (AMBDA.LT.1.) GO TO 43                                        2600
      SUM = (ENN-SUMN)/ENN                                             2610
      IF (SUM.LT.0.) SUM = -SUM                                        2620
      IF (SUM.GT.0.5E-5) GO TO 43                                      2630
```

```
      DO 130 J=1,NS                                                     2640
      IF (IUSE(J).LT.0) GO TO 130                                       2650
      AA= DELN(J)/SUMN                                                  2660
      IF(AA.LT.0.)  AA=-AA                                              2670
      IF (IUSE(J).EQ.0) AA = AA*EN(J,NPT)                               2680
  129 IF(AA.GT.0.5E-5)  GO TO 43                                        2690
  130 CONTINUE                                                          2700
   13 CONVG= .TRUE.                                                     2710
      IF(TT     .LT.TLOW.OR.TT     .GT.THIGH)WRITE (6,306)TT     ,NPT  2720
  306 FORMAT(17H0THE TEMPERATURE=E12.4,26H IS OUT OF RANGE FOR POINT,I5) 2730
      IF(ITNUMB.NE.0) GO TO 160                                         2740
      WRITE(6,973) ITN,NPT                                              2750
  973 FORMAT(1HL,I2,69H ITERATIONS DID NOT SATISFY CONVERGENCE REQUIREME 2760
     1NTS FOR THE POINT        I5)                                      2770
      IF (.NOT.HP.OR.NPT.NE.1.OR.NC.EQ.0.OR.TT.GT.100.)  GO TO 873      2780
      WRITE(6,674)                                                      2790
      TT = T(1)                                                         2800
      RETURN                                                            2810
C                                                                       2820
C     CONVERGENCE TESTS ARE SATISFIED, TEST CONDENSED SPECIES.          2830
C                                                                       2840
  160 IF(NC.EQ.0) GO TO 143                                             2850
      SIZEF = 0.                                                        2860
      INC = 0                                                           2870
      DO 170 J = 1,NS                                                   2880
      IF (IUSE(J).EQ.0 .OR. IUSE(J).EQ.-10000) GO TO 170                2890
      INC = INC + 1                                                     2900
      IF(IDEBUG) WRITE(6,144)(SUB(J,I),I=1,3),TEMP(INC,1),TEMP(INC,2),  2910
     1IUSE(J),EN(J,NPT)                                                 2920
  144 FORMAT (1H0,3A4,2F10.3,3X,5HIUSE=,I4,E15.7)                       2930
      IF (EN(J,NPT))  146,148,169                                       2940
  146 IF (J.NE.JSOL .AND. J .NE.JLIQ) GO TO 147                         2950
      JSOL = 0                                                          2960
      JLIQ = 0                                                          2970
  147 IQ1 = IQ1 - 1                                                     2980
      EN(J,NPT) = 0.                                                    2990
      GO TO 166                                                         3000
  148 KG = 1                                                            3010
```

```
      IF(IUSE(J).EQ.-IUSE(J+1)) GO TO 154                              3020
  151 IF(J.EQ.1.OR.IUSE(J).NE.-IUSE(J-1)) GO TO 153                    3030
      KG = -1                                                          3040
  154 JKG = J + KG                                                     3050
      IF (EN(JKG,NPT).LT.0.) GO TO 170                                 3060
      TMELT = TEMP(INC,1)                                              3070
      IMP = INC + KG                                                   3080
      IF(TMELT.EQ.TEMP(IMP,2  )) GO TO 158                             3090
      TMELT = TEMP(INC,2)                                              3100
      IF (TMELT.EQ.TEMP(IMP,1)) GO TO 157                              3110
      WRITE (6,156)                                                    3120
  156 FORMAT (50H03 PHASES OF A CONDENSED SPECIES ARE OUT OF ORDER      3130
C                                                                      3140
C  JTH SPECIES A SOLID (EN=0), (J+KG)TH SPECIES A LIQUID (EN IS +)     3150
C                                                                      3160
  157 IF(TT.GT.TMELT) GO TO 169                                        3170
      IF (TP.AND.TT.EQ.TMELT) GO TO 169                                3180
      IF (TP)  GO TO 1165                                              3190
      IF (TT.LE.TMELT-150.) GO TO 1165                                 3200
      JSOL = J                                                         3210
      JLIQ = JKG                                                       3220
      GO TO 159                                                        3230
C                                                                      3240
C  JTH SPECIES A LIQUID(EN=0), (J+KG)TH SPECIES A SOLID (EN IS +)      3250
C                                                                      3260
  158 IF (TT.LT.TMELT) GO TO 169                                       3270
      IF (TP.AND.TT.EQ.TMELT) GO TO 169                                3280
      IF (TP)  GO TO 1165                                              3290
      IF (TT.GE.TMELT+150.) GO TO 1165                                 3300
      JSOL = JKG                                                       3310
      JLIQ = J                                                         3320
  159 TLN = ALOG (TMELT)                                               3330
      TT = TMELT                                                       3340
      EN(JKG,NPT) = .5 * EN(JKG,NPT)                                   3350
      EN(J,NPT) = EN(JKG,NPT)                                          3360
      GO TO 165                                                        3370
C                                                                      3380
C  WRONG PHASE INCLUDED FOR T INTERVAL, SWITCH EN                      3390
```

```
C                                                                              3400
 1165 EN(J,NPT) = EN (JKG, NPT)                                                3410
      IUSE(J) = -IUSE(J)                                                       3420
      IUSE (JKG) = -IUSE(JKG)                                                  3430
      EN(JKG,NPT)= 0.                                                          3440
      GO TO 40                                                                 3450
  153 IF (TT.LT.TEMP(INC,1) .AND.TEMP(INC,1).NE.TLOW) GO TO 169                3460
      IF (TT.GT.TEMP(INC,2)) GO TO 169                                         3470
C                                                                              3480
C                                                                              3490
      SUM = 0.                                                                 3500
      DO 167 I = 1,L                                                           3510
      SUM = SUM + A(I,J)*X(I)                                                  3520
  167 CONTINUE                                                                 3530
      DELF = H0(J)-S(J)-SUM                                                    3540
      IF(IDEBUG) WRITE(6,168)DELF,SIZEF                                        3550
  168 FORMAT (17H GO-SUM(AIJ*PI) =E15.7,10X,18HPREVIOUS DELTA G =,E15.7)       3560
      IF(DELF.GE.SIZEF .OR. DELF.GE.0.) GO TO 169                              3570
      SIZEF = DELF                                                             3580
      JDELF = J                                                                3590
  169 IF(INC.EQ.NC) GO TO 1160                                                 3600
  170 CONTINUE                                                                 3610
 1160 IF (SIZEF.EQ.0.) GO TO 143                                               3620
      J = JDELF                                                                3630
  165 IQ1 = IQ1 + 1                                                            3640
  166 IUSE(J) = - IUSE(J)                                                      3650
   40 CONVG = .FALSE.                                                          3660
  143 TN = NUMB                                                                3670
      WRITE(6,771)NPT,(X(IL),IL=1,L),TN                                        3680
  771 FORMAT (I3,14F9.3)                                                       3690
      ITNUMB = ITN                                                             3700
      GO TO 43                                                                 3710
C                                                                              3720
C     CALCULATE EQUILIBRIUM PROPERTIES                                         3730
C                                                                              3740
  171 SSUM(NPT) = 0.                                                           3750
      IF(JLIQ.NE.0) EN(JSOL,NPT)=ENSOL                                         3760
      DO 183 J=1,NS                                                            3770
```

```
      IF (NPT.EQ.1) SS0 = SS0 + EN(J,1)*S(J)                                3780
      WRITE(6,7689)SS0,EN(J,1),S(J)
 7689 FORMAT(1H0,4HSS0=E10.3,2X,3HEN=E10.3,2X,2HS=E10.3)
      SS = S(J)                                                             3790
      IF(IUSE(J).EQ.0)  SS=SS-ENLN(J)-TM                                    3800
      SSUM(NPT) = SSUM(NPT)+SS*EN(J,NPT)                                    3810
  183 CONTINUE                                                              3820
      IF(.NOT.IC)  GO TO 178                                                3830
      DLVPT(NPT) = -1.                                                      3840
      DLVTP(NPT) = 1.                                                       3850
      CPR(NPT) = CPSUM                                                      3860
      GO TO 199                                                             3870
  178 SUM = 0.                                                              3880
      DO 179 J = 1,L                                                        3890
      SUM = SUM + PROW(J)*X(J)                                              3900
  179 CONTINUE                                                              3910
      DLVPT(NPT) = -2.+SUM/ENN+ X(IQ1)                                      3920
  184 IF(JLIQ.EQ.0)  GO TO 199                                              3930
      IUSE(JLIQ) = -IUSE(JLIQ)                                              3940
      HSUM(NPT) = HSUM(NPT)+EN(JLIQ,NPT)*(H0(JLIQ)-H0(JSOL))                3950
      IQ1 = IQ1+1                                                           3960
      GAMMAS(NPT) = -1./DLVPT(NPT)                                          3970
      GO TO 186                                                             3980
  199 GAMMAS(NPT) = -1./(DLVPT(NPT)+(DLVTP(NPT)**2)*ENN/CPR(NPT))           3990
  186 TTT(NPT) = TT                                                         4000
      PPP(NPT) = PP                                                         4010
      CPRF(NPT) = CPSUM                                                     4020
      HSUM(NPT) = HSUM(NPT)*TT                                              4030
      WM(NPT) = 1./ENN                                                      4040
  200 IF (.NOT.IDEBUG) RETURN                                               4050
      WRITE(6,201) NPT,PCP(NPT),PP,TT,HSUM(NPT),SSUM(NPT),WM(NPT),CPR(NP    4060
     1T),DLVPT(NPT),DLVTP(NPT),GAMMAS(NPT)                                  4070
  201 FORMAT (7H0POINT=I3,3X,4HPCP=E13.6,3X,2HP=E13.6,3X,2HT=E13.6,3X,4H    4080
     1H/R=E13.6,3X,4HS/R=E13.6//3X,3HMW=E13.6,3X,5HCP/R=E13.6,3X,6HDLVPT    4090
     2=E13.6,3X,6HDLVTP=E13.6,3X,9HGAMMA(S)=E13.6 )                         4100
      GO TO 1000                                                            4110
C                                                                           4120
C     ERROR, SET TT=0                                                       4130
```

```
C                                                                       4140
  873 TT=0.                                                             4150
      NPT = NPT-1                                                       4160
 1000 RETURN                                                            4170
      END                                                               4180
```

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$IBFTC CECS17  DECK
C                                                                       10
      SUBROUTINE FROZEN                                                 20
C                                                                       30
C     (FROZEN COMPOSITION EXPANSION ONLY)                               40
C                                                                       50
      LOGICAL EQL,FROZ,CONVG                                            60
C                                                                       70
      COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)       80
     1 ,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13)  90
     2,TOTN(13)                                                        100
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)   110
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)            120
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)  130
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2) 140
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)         150
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15) 160
     4 ,RHOP,RMW(15),TLN                                               170
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM  180
     1   ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ 190
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                      200
      COMMON/PERF/PCP(26),VMOC(13),SPIM(13),VACI(13),SUBAR(13),SUPAR(13) 210
     1 ,CPRF(13),AEAT(13),CSTR,EQL,FROZ,SS0                            220
      COMMON/OUPT/FMT(30),FP(4),FT(4),FH(4),FS(4),FM(4),FV(4),FD(4)     230
     1   ,FC(4),FG(4),FB,FMT13,F1,F2,F3,F4,F5,FL(4),FMTI9,FA1,FA2      240
     2   ,FR1,FC1,FN(4),FR(4),FA(4),FI(4),FMT9X,F0,FRI(2)              250
      ITROT = 3                                                         260
      EQL =.FALSE.                                                      270
      NPT = 2                                                           280
       TT = TTT(1)                                                      290
      TLN=ALOG(TT)                                                      300
      WRITE(6,9009)TT,SS0,CPRF(1),PCP(1),WM(1),TLN,GAMMAS(1)
 9009 FORMAT(1H0,3HTT-E10.3,4HSS0=E10.3,5HCPRF=E10.3,4HPCP=E10.3,
     13HWM=E10.3,4HTLN=E10.3,7HGAMMAS=E10.3)
      GAMMAS(1) = CPRF(1)/(CPRF(1)-1./WM(1))                            310
      CPR(1) = CPRF(1)                                                  320
      PCP(2) = ((GAMMAS(1)+1.)/2.)**(GAMMAS(1)/(GAMMAS(1)-1.))          330
      DATA(1) = 2./(GAMMAS(1) + 1.)                                     340
```

```
      TLN = TLN + ALOG(DATA(1))                                          350
      DO 902  IP=2,NP                                                    360
      IF(NPT.EQ.2)  GO TO 45                                             370
      PCP(NPT) = P(1)/P(IP)                                              380
   45 CONVG = .FALSE.                                                    390
      PCPLN= ALOG(PCP(NPT))                                              400
      S0 = SS0 -PCPLN/WM(1)                                              410
      SUMH = 0.                                                          420
   51 TT=EXP(TLN)                                                        430
      SUMS=0.                                                            440
      JS1 = 1                                                            450
      NNN = NPT                                                          460
      NPT = 1                                                            470
      CALL CPHS                                                          480
      NPT = NNN                                                          490
      DO 60 J=1,NS                                                       500
      IF(EN(J,1).EQ.0.)  GO TO 60                                        510
      SUMS = SUMS + S(J)*EN(J,1)                                         520
      IF(CONVG) SUMH=SUMH+H0(J)*EN(J,1)                                  530
   60 CONTINUE                                                           540
      IF (CONVG) GO TO 81                                                550
      DLNT=(SUMS-S0)/CPSUM                                               560
      TLN=TLN-DLNT                                                       570
      IF(DLNT.LT.0.) DLNT=-DLNT                                          580
      IF(DLNT.LT.0.5E-4)  CONVG=.TRUE.                                   590
      GO TO 51                                                           600
   81 TTT(NPT)= TT                                                       610
      SSUM(NPT)= SSUM(1)                                                 620
      HSUM(NPT)= TT*SUMH                                                 630
      GAMMAS(NPT)= CPSUM/(CPSUM-1./WM(1))                                640
      IF(IP.GT.2)  GO TO 90                                              650
C                                                                        660
C     THROAT CALCULATIONS                                                670
C                                                                        680
      DH = HSUM(1)-HSUM(2)                                               690
      DHSTAR = DH-(GAMMAS(2)*TT/(2.*WM(1)))                              700
      DH = DHSTAR/DH                                                     710
      IF(DH.LT.0.)  DH=-DH                                               720
```

```
      IF(DH.LE.0.4E-4.OR.ITROT.EQ.0) GO TO 90                                  730
      PCP(2) = PCP(2)/(1.+2.*DHSTAR*WM(1)/(TT*(GAMMAS(2)+1.)))                 740
      P(2) = P(1)/PCP(2)                                                       750
      ITROT = ITROT-1                                                          760
      GO TO 45                                                                 770
   90 WM(NPT)= WM(1)                                                           780
      PPP(NPT) = P(IP)                                                         790
      CPR(NPT)= CPSUM                                                          800
      K = 0                                                                    810
      IF (TT.LT.(TLOW-150.))GO TO 903                                          820
      IF(NC.EQ.0) GO TO 700                                                    830
      INC =0                                                                   840
      DO 901 I=1,NS                                                            850
      IF(IUSE(I).EQ.0.OR.IUSE(I).EQ.-10000) GO TO 901                          860
      INC = INC+1                                                              870
      IF(EN(I,1).EQ.0.) GO TO 901                                              880
      IF (TT.LT.(TEMP(INC,1)-50.).OR.TT.GT.(TEMP(INC,2)+50.))GO TO 903         890
  901 CONTINUE                                                                 900
  700 IF ( IP.EQ.NP) GO TO 863                                                 910
      K = NPT                                                                  920
      IF (NPT.NE.13) GO TO 870                                                 930
      GO TO 863                                                                940
  903 NPT = NPT - 1                                                            950
  863 CALL RKTOUT                                                              960
      GO TO 1000
  865 IF (K.EQ.0) GO TO 1000                                                   980
      NPT = 2                                                                  990
  870 NPT = NPT + 1                                                           1000
  902 CONTINUE                                                                1010
 1000 RETURN                                                                  1020
      END                                                                     1030
```

```
$IBFTC CECS9   DECK
C                                                                       10
      SUBROUTINE HCALC                                                  20
C                                                                       30
C  CALCULATE ENTHALPY FOR PROPELLANT USING COEFFICIENTS                 40
C                                                                       50
      LOGICAL MOLES                                                     60
      DIMENSION NUM(15,5),WS(2)                                         70
C                                                                       80
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)   90
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)            100
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)  110
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2) 120
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)         130
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15) 140
     4 ,RHOP,RMW(15),TLN                                               150
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM  160
     1  ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ 170
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                      180
C                                                                       190
      EQUIVALENCE (ANUM,NUM),(L,NLM),(J,JS1)                            200
C                                                                       210
      DATA AG/1HG/,IZERO/2H00/,OX/1HO/                                  220
C                                                                       230
C  IS TT IN RANGE                                                       240
C                                                                       250
      IF(TT.LT.(TLOW-100.).OR.TT.GT.(THIGH+1000.))GO TO 75              260
      WS(1) = 0.                                                        270
      WS(2) = 0.                                                        280
      HPP(1)=0.                                                         290
      HPP(2)=0.                                                         300
      AC(1)=0.                                                          310
      AC(2)=0.                                                          320
      DO 900 N=1,NREAC                                                  330
      K=2                                                               340
      IF(FOX(N).EQ.OX)K=1                                               350
      PCWT=PECWT(N)                                                     360
      IF(MOLES)PCWT=PCWT*RMW(N)                                         370
```

```
      WS(K) = WS(K) + PCWT                                                    380
      IF(NAME(N,5).NE.IZERO)GO TO 500                                         390
      J    = NUM(N,5)                                                         400
      IF (J.NE.0)  GO TO 90                                                   410
      DO 10 J=1,L                                                             420
      DATA(J)=0.                                                              430
   10 CONTINUE                                                                440
      DO 40 I=1,4                                                             450
      IF(ANUM(N,I).EQ.0.)GO TO 50                                             460
      DO 20 J=1,L                                                             470
      IF(LLMT(J).EQ.NAME(N,I)) GO TO 30                                       480
   20 CONTINUE                                                                490
   30 DATA(J)=ANUM(N,I)                                                       500
   40 CONTINUE                                                                510
   50 IS=0                                                                    520
      DO 70 J=1,NS                                                            530
      IF(IUSE(J).EQ.0)GO TO 55                                                540
      IS = IS+1                                                               550
      IF(FAZ(N).EQ.AG)GO TO 70                                                560
      IF(TT.GT.TEMP(IS,2).AND.TEMP(IS,2).NE.THIGH)  GO TO 70                  570
      IF(TT.LT.TEMP(IS,1).AND.TEMP(IS,1).NE.TLOW)  GO TO 70                   580
      GO TO 56                                                                590
   55 IF(FAZ(N).NE.AG) GO TO 70                                               600
   56 DO 60 I=1,L                                                             610
      IF(A(I,J).NE.DATA(I))  GO TO 70                                         620
   60 CONTINUE                                                                630
      NUM(N,5) = J                                                            640
      GO TO 90                                                                650
   70 CONTINUE                                                                660
      DELN(J)= EN(J,NPT)                                                      700
      EN(J,NPT) = 1.                                                          710
      CALL CPHS                                                               720
      EN(J,NPT) = DELN(J)                                                     730
      NS = NSS                                                                740
      IF (H0(J).GT.-.01 .AND. H0(J).LT..01) H0(J) = 0.                        750
      RTEMP(N) = TT                                                           760
      ENTH(N) = H0(J)*R*TT                                                    770
      AC(K)=AC(K)+CPSUM*PCWT/RMW(N)                                           780
```

```
  500 HPP(K)=HPP(K)+ENTH(N)*PCWT/RMW(N)                                    790
  900 CONTINUE                                                             800
      DO 950 K=1,2                                                         810
      IF(WS(K).EQ.0.)GO TO 950                                             820
      HPP(K)=HPP(K)/WS(K)                                                  830
      AC(K)=AC(K)/WS(K)                                                    840
      GO TO 80                                                             670
   90 NSS = NS                                                             680
      NS = J                                                               690
  950 CONTINUE                                                             850
      HSUB0 = (WP(1)*HPP(1)+WP(2)*HPP(2))/(WP(1)+WP(2))                    860
      GO TO 1000                                                           870
   75 WRITE(6,76)                                                          880
   76 FORMAT(50H0REACTANT TEMPERATURE OUT OF RANGE OF THERMO DATA )        890
   80 WRITE(6,85) N                                                        900
   85 FORMAT(1H0,I2,34H TH REACTANT IS NOT IN THERMO DATA )                910
 1000 RETURN                                                              920
      END                                                                 930
```

```
$IBFTC CECS14  DECK                                                              10
C                                                                                20
C  ROCKET PERFORMANCE PERAMETERS                                                30
C                                                                                40
      SUBROUTINE RKTOUT                                                          50
C                                                                                60
      LOGICAL EQL,FROZ ,TP,HP,SP,HPSP,TPSP,SHOCK                                 70
C                                                                                80
      DIMENSION NV(13),Z(10,4),RHOISP(13)                                        90
C                                                                               100
      COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)               110
     1 ,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13)          120
     2  ,TOTN(13)                                                               130
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)           140
     1 ,DELN(150),A(15,150),SUB(150,3),9USE(150),TEMP(50,2)                     150
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)           160
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2)        170
     2 ,HPP(2),RH0(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)                 180
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15)        190
     4 ,RHOP,RMW(15),TLN                                                        200
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM          210
     1  ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ         220
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                               230
      COMMON/PERF/PCP(26),VMOC(13),SPIM(13),VACI(13),SUBAR(13),SUPAR(13)        240
     1 ,CPRF(13),AEAT(13),CSTR,EQL,FROZ,SS0                                     250
      COMMON/OUPT/FMT(30),FP(4),FT(4),FH(4),FS(4),FM(4),FV(4),FD(4)             260
     1  ,FC(4),FG(4),FB,FMT13,F1,F2,F3,F4,F5,FL(4),FMT19,FA1,FA2                270
     2  ,FR1,FC1,FN(4),FR(4),FA(4),FI(4),FMT9X,F0,FRI(2)                        280
      COMMON/GASES/TAB(3,12,13),NMIX                                            290
      COMMON/SUNUP/SUN(3,40,2)                                                  300
      COMMON/CASENO/LST                                                         310
      COMMON/TAPE/IPROT                                                         320
      COMMON/MOLFRC/ZFRAC(40),KF
C
      EQUIVALENCE (V,NV),(Z,H0)
C
      DATA EXIT/4HEXIT/
C
```

```
      LSP=LST                                                                  330
      IF(EQL) WRITE (6,37)                                                     340
   37 FORMAT(1H1/24X,84HTHEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBR       350
     1IUM COMPOSITION DURING EXPANSION         //)                            360
      IF (.NOT.EQL) WRITE (6,38)                                               370
   38 FORMAT(1H1,26X,78HTHEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN C       380
     1OMPOSITION DURING EXPANSION         //)                                  390
      IF (TPSP) WRITE (6,737)                                                  400
  737 FORMAT (52X,28HAT AN ASSIGNED TEMPERATURE                                410
      V(1) = PPP(1)*14.696006                                                  420
      WRITE (6,40) V(1)                                                        430
   40 FORMAT(5H PC = ,F8.1,5H PSIA)                                            440
      CALL OUT1                                                                450
      NEX = NPT - 2                                                            460
      DO 862 I = 1,NEX                                                         470
  862 V(I) = EXIT                                                              480
      WRITE(6,48) (V(I),I=1,NEX)                                               490
   48 FORMAT(1H0,16X,16HCHAMBER    THROAT   ,11(5X,A4))                        500
C                                                                              510
C     PRESSURE RATIOS                                                          520
C                                                                              530
      DO 45 I=1,NPT                                                            540
      K= 2*I+3                                                                 550
      FMT(K)= F3                                                               560
      IF (PCP(I).GE.1000.) FMT(K)=F2                                           570
      IF (PCP(I).GE.10000.)FMT(K)=F1                                           580
      IF (PCP(I).GE.1000000.)FMT(K) = F0                                       590
   45 CONTINUE                                                                 600
      WRITE (6,FMT) FR1,FB,FB,FB,(PCP(J),J=1,NPT)                              610
      CALL OUT2                                                                620
C                                                                              630
      AGV = 9.80665                                                            640
      DO 202 K=2,NPT                                                           650
      SPIM(K) = (2.*RR*(HSUM(1)-HSUM(K)))**.5/AGV                              660
C                                                                              670
C  AW (A/W) IN UNITS OF SEC/ATM                                                680
C                                                                              690
      AW = RR*TTT(K)/(PPP(K)*          WM(K)*SPIM(K)*AGV**2)
```

```
      IF(K.NE.2)GO TO 200                                                    700
      AWT=AW                                                                 710
      CSTR=32.174*P(1)*AWT                                                   720
  200 AEAT(K)=AW/AWT                                                         730
      VACI(K)=SPIM(K)+PPP(K)*AW                                              740
      IF (SONVEL(K).NE.0.) VMOC(K)=SPIM(K)*AGV/SONVEL(K)                     750
      NV(K)= CSTR + .5                                                       760
  202 CONTINUE                                                               770
C                                                                            780
C   MACH NUMBER                                                              790
C                                                                            800
      VMOC(1)=0.                                                             810
      IF(GAMMAS(2).EQ.0.) VMOC(2)=0.                                         820
      FMT(7) = F3                                                            830
      WRITE(6,FMT)(FN(I),I=1,4),(VMOC(J),J=1,NPT)                            840
      DO 520 JAB=1,NPT
  520 TAB(LSP,4,JAB)=VMOC(JAB)
      WRITE (6,208)                                                          850
  208 FORMAT (1H )                                                           860
C                                                                            870
C   C*                                                                       880
C                                                                            890
      FMT(4) = FMT9X                                                         900
      FMT(5) = FMT13                                                         910
      FMT(6) = FMTI9                                                         920
      FMT(7) = FB                                                            930
      WRITE(6,FMT)(FR(I),I=1,4),(NV(J),J=2,NPT)                              940
C                                                                            950
C   CF - THRUST COEFICIENT                                                   960
C                                                                            970
      FMT(6) = FMT(8)                                                        980
      FMT(7) = F3                                                            990
      DO 212  I=2,NPT                                                       1000
  212 V(I)=32.174*SPIM(I)/CSTR                                              1010
      WRITE(6,FMT)FC1,FB,FB,FB,(V(J),J=2,NPT)                               1020
C                                                                           1030
C   AREA RATIO                                                              1040
C                                                                           1050
```

```
      FMT(5) = FB                                                        1060
      DO 214 I = 2,NPT                                                   1070
      K = 2*I+3                                                          1080
      FMT(K) = F4                                                        1090
      IF (AEAT(I).GE.1.) FMT(K) = F3                                     1100
      IF (AEAT(I).GE.10.) FMT(K) = F2                                    1110
      IF (AEAT(I).GE.100.) FMT(K) = F1                                   1120
  214 CONTINUE                                                           1130
      WRITE(6,FMT)FA1,FA2,FB,FB,(AEAT(J),J=2,NPT)                        1140
      DO 530 JAB=1,NPT
  530 TAB(LSP,2,JAB)=AEAT(JAB)
C                                                                        1150
C   VACUUM IMPULSE                                                       1160
C                                                                        1170
      FMT(5) = FMT13                                                     1180
      FMT(7) = F1                                                        1190
      WRITE(6,FMT)(FA(I),I=1,4),(VACI(J),J=2,NPT)                        1200
C                                                                        1210
C   SPECIFIC IMPULSE                                                     1220
C                                                                        1230
      WRITE(6,FMT)(FI(I),I=1,4),(SPIM(J),J=2,NPT)                        1240
      DO 308 J = 2,NPT                                                   1250
  308 RHOISP(J) = SPIM(J) * RHOP                                         1260
      WRITE (6,FMT) (FRI(I),I=1,2),FB,FB,(RHOISP(J),J=2,NPT)             1270
      WRITE (6,208)                                                      1280
      FMT(4) = FB                                                        1290
      FMT(5) = FMT13                                                     1300
      FMT(7) = F5                                                        1310
      IF(EQL)  GO TO 312                                                 1320
      WRITE(6,310)                                                       1330
  310 FORMAT(15HOMOLE FRACTIONS //)                                      1340
C                                                                        1350
C   MOLE FRACTIONS - FROZEN                                              1360
C                                                                        1370
      LINE = 0                                                           1380
      KF=0
      DO 430 K =1,NS                                                     1390
      V(LINF+1) = EN(K,1)/TOTN(1)                                        1400
```

```
      IF (V(LINE+1).LT.(5.E-6))  GO TO 424                              1410
      LINE = LINE+1                                                     1420
      Z(LINE,1) = SUB(K,1)                                              1430
      Z(LINE,2) = SUB(K,2)                                              1440
      Z(LINE,3) = SUB(K,3)                                              1450
      Z(LINE,4) = V(LINE)                                               1460
      IF(V(LINE).LE..05) GO TO 561
      KF=KF+1
      ZFRAC(KF)=V(LINE)
      DO 560 JAB=1,NPT
  560 TAB(LSP,KF+8,JAB)=V(LINE)
      SUN(LSP,KF,1)=SUB(K ,1)
      SUN(LSP,KF,2)=SUB(K ,2)
      WRITE(6,562)KF,SUN(LSP,KF,1),SUN(LSP,KF,2),SUB(K,1),SUB(K,2),
     $ZFRAC(KF),V(LINE)
  562 FORMAT(1H0,I5,5X,2A6,5X,2A6,5X,E10.3,5X,E10.3)
  561 CONTINUE
  424 IF (LINE.NE.4.AND.K.NE.NS)  GO TO 430                             1470
      IF (LINE.EQ.0)  GO TO 312                                         1480
      WRITE (6,426) (Z(LN,1),Z(LN,2),Z(LN,3),Z(LN,4),LN=1,LINE)         1490
  426 FORMAT (1H ,4(3A4,F9.5,7X))                                       1500
      LINE = 0                                                          1510
  430 CONTINUE                                                          1520
  312 CALL OUT3                                                         1530
 1000 RETURN                                                            1540
      END                                                               1550
```

```
$IBFTC CECS19  DECK
      BLOCK DATA
      COMMON/OUPT/FMT(30),FP(4),FT(4),FH(4),FS(4),FM(4),FV(4),FD(4)          100
     1   ,FC(4),FG(4),FB,FMT13,F1,F2,F3,F4,F5,FL(4),FMT19,FA1,FA2            110
     2   ,FR1,FC1,FN(4),FR(4),FA(4),FI(4),FMT9X,F0,FRI(2)                    120
C                                                                           540
C      INFORMATION USED IN VARIABLE OUTPUT FORMAT                           550
C                                                                           560
      DATA FMT/3H(1H,4H,3A4,4H,A2,,3HF9.,1H ,3HF9.,1H ,3HF9.,1H ,3HF9.,1      570
     11H ,3HF9.,1H ,3HF9.,1H ,3HF9.,1H ,3HF9.,1H ,3HF9.,1H ,3HF9.,1H ,3HF    580
     29.,1H ,3HF9.,1H ,3HF9.,1H ,1H)/, FB,F0,F1,F2,F3,F4,F5/1H  ,2H0,,2H     590
     31,,2H2,,2H3,,2H4,,2H5,/,FMT13/2H13/,FMT9X/3H9X,/,FMTI9/3HI9,/          600
      DATA                                FP/4HP, A,4HTM  ,2H  ,1H /          610
     1,FT/4HT, D,4HEG K,4H    ,2H  /,FH/4HH, C,4HAL/G,2H  ,1H /              620
     2,FS/4HS, C,4HAL/(,4HG)(K,2H) /,FM/4HM, M,4HOL W,2HT ,1H /              630
     3,FV/4H(DLV,4H/DLP,4H)T  ,2H  /,FD/4H(DLV,4H/DLT,2H)P,1H /              640
     4,FC/4HCP, ,4HCAL/,4H(G)(,2HK)/,FG/4HGAMM,4HA (S,2H) ,1H /              650
     5,FL/4HSON ,4HVEL,,4HM/SE,2HC /                                         660
C                                                                           670
C      INFORMATION USED IN PERFORMANCE OUTPUT                               680
C                                                                           690
      DATA FR1/4HPC/P/, FC1/2HCF/,    FN/4HMACH,4H NUM,4HBER ,1H /          700
     1,FR/4HCSTA,4HR, F,4HT/SE,2HC  /,FI/4HI, L,4HB-SE,4HC/LB,1H /           710
     2,FA/4HIVAC,4H,LB-,4HSEC/,2HLB /,FA1/4HAE/A/,FA2/1HT/                   720
     3,FRI/4HRHOI,2HSP/                                                      730
      END
```

```
$ORIGIN        F
$*
$IBFTC CECS8   DECK
      SUBROUTINE OUT1                                                          10
C                                                                              20
      DOUBLE PRECISION G,X                                                     30
      LOGICAL EQL,FROZ ,TP,HP,SP,HPSP,TPSP,MOLES                               40
C                                                                              50
      DIMENSION NV(13),Z(10,3),HEAD(15),YX(5),YN(5)                            60
C                                                                              70
      COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)              80
     1 ,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13)         90
     2  ,TOTN(13)                                                            100
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)        110
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)                  120
      COMMON/MISC/ENN,SUMN,TT,SO,ATOM(3,101),LLMT(15),BO(15),BOP(15,2)        130
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUBO,AC(2),AM(2)      140
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)               150
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15)      160
     4 ,RHOP,RMW(15),TLN                                                      170
      COMMON /DOUBLE/ G(20,21), X(20)                                          180
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM         190
     1  ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ        200
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                             210
      COMMON/PERF/PCP(26),VMOC(13),SPIM(13),VACI(13),SUBAR(13),SUPAR(13)       220
     1 ,CPRF(13),AEAT(13),CSTR,EQL,FROZ,SSO                                   230
      COMMON/OUPT/FMT(30),FP(4),FT(4),FH(4),FS(4),FM(4),FV(4),FD(4)            240
     1  ,FC(4),FG(4),FB,FMT13,F1,F2,F3,F4,F5,FL(4),FMT19,FA1,FA2               250
     2  ,FR1,FC1,FN(4),FR(4),FA(4),FI(4),FMT9X,F0,FRI(2)                       260
C                                                                              270
      EQUIVALENCE (V,NV),(Z,H0),(IB,FB)                                        280
      COMMON/GASES/TAB(3,12,13),NMIX
      COMMON/CASENO/LST
C                                                                              290
C     HEAD=(1H ,2A4,5  (A2,F8.5,3X),5  X,F7.5,F13.3,4X,A1,F10.2,F9.4)          300
C                                                                              310
      DATA HEAD/4H(1H ,4H,2A4,2H,5,4H(A2,,4HF8.5 ,4H,3X),2H,5 ,2HX,            320
     1    ,4HF7.5 ,4H,F13 ,4H.3,4 ,4HX,A1 ,4H,F10 ,4H.2,F ,4H9.4)/             330
```

```
      DATA FUEL/4HFUEL/,OXID/4HOXID/,ANT/3HANT/,OX/1HO/,IZ/2H00/
     1       ,YN/2H,1, 2H,2, 2H,3, 2H,4, 2H,5 /,F75/4HF7.5/
     2       ,YX/3H,57,3H,44,3H,31,3H,18,2H,5 /,F73/4HF7.3/
      LSP=LST
C
      IF(KASE.NE.0) WRITE (6,3) KASE
    3 FORMAT (9H CASE NO. ,I5)
      IF(.NOT.MOLES) WRITE(6,5)
    5 FORMAT (77X,46HWT FRACTION  ENTHALPY  STATE   TEMP    DENSITY/
     1 10X,16HCHEMICAL FORMULA,51X,21H(SEE NOTE)    CAL/MOL,10X,5HDEG K,
     2 4X,4HG/CC )
      IF(MOLES) WRITE(6,6)
    6 FORMAT (79X,5HMOLES,7X,  33HENTHALPY  STATE   TEMP    DENSITY/
     1 10X,16HCHEMICAL FORMULA,66X,7HCAL/MOL,10X,13HDEG K    G/CC )
      DO 15 N=1,NREAC
      IF(FOX(N).EQ.FOX(N-1))GO TO 11
      IF(FOX(N).NE.OX)GO TO 10
      HD1 = OXID
      HD2 = ANT
      GO TO 11
   10 HD1 = FUEL
      HD2 = FB
   11 DO 13 J=1,5
      IF(NAME(N,J).EQ.IZ.OR.NAME(N,J).EQ.IB)  GO TO 14
   13 CONTINUE
      J=6
   14 J=J-1
      HEAD(3)=YN(J)
      HEAD(7)=YX(J)
      HEAD(9) = F75
      IF(PECWT(N).GE.10.)  HEAD(9)=F73
      WRITE(6,HEAD)HD1,HD2,(NAME(N,JJ),ANUM(N,JJ),JJ=1,J),PECWT(N),ENTH(
     1N), FAZ(N),RTEMP(N),DENS(N)
   15 CONTINUE
      FPC = 100./(1.+WP(1))
      WRITE(6,20) WP(1),FPC,EQRAT,RHOP
   20 FORMAT (1H0,15X, 4HO/F=, F8.4,4X,13HPERCENT FUEL=,F8.4,4X,
     1  19HEQUIVALENCE RATIO= ,F7.4,4X,8HDENSITY=,F8.4//)
```

```
C                                                                       710
      AGV = 9.80665                                                     720
      DO 25 I = 1,NPT                                                   730
      TOTN(I) = 0                                                       740
      DO 25 J = 1,NS                                                    750
      TOTN(I) = TOTN(I) + EN(J,I)                                       760
   25 CONTINUE                                                          770
      FMT(4)= FMT(6)                                                    780
      RETURN                                                            790
C                                                                       800
      ENTRY OUT2                                                        810
C                                                                       820
C    PRESSURE                                                           830
C                                                                       840
      DO 55 I=1,NPT                                                     850
      K= 2*I+3                                                          860
      FMT(K)= F4                                                        870
      IF (PPP(I).GE.1.) FMT(K)=F3                                       880
      IF (PPP(I).GE.10.) FMT(K)=F2                                      890
      IF (PPP(I).GE.100.) FMT(K)=F1                                     900
   55 CONTINUE                                                          910
      WRITE (6,FMT)(FP(I),I=1,4),(PPP(J),J=1,NPT)                       920
      DO 500 JAB=1,NPT
  500 TAB(LSP,5,JAB)=PPP(JAB)*14.7*144.
C                                                                       930
C    TEMPERATURE                                                        940
C                                                                       950
      DO 65 I=1,NPT                                                     960
      NV(I)= TTT(I)+.5                                                  970
   65 CONTINUE                                                          980
      FMT(4)= FMT13                                                     990
      FMT(5)= FMT19                                                    1000
      WRITE (6,FMT)(FT(I),I=1,4),(NV(J),J=1,NPT)                       1010
      DO 510 JAB=1,NPT
  510 TAB(LSP,6,JAB)=FLOAT(NV(JAB))*1.8
C                                                                      1020
C    ENTHALPY                                                          1030
C                                                                      1040
```

```
      DO 75 I=1,NPT                                                    1050
      V(I) = HSUM(I) * R                                               1060
   75 CONTINUE                                                         1070
      FMT(5)= FB                                                       1080
      FMT(7)= F1                                                       1090
      WRITE (6,FMT)(FH(I),I=1,4),(V(J),J=1,NPT)                        1100
      DO 515 JAB=1,NPT
  515 TAB(LST,1,JAB)=V(JAB)*1.8*778.*32.174
C                                                                      1110
C   ENTROPY                                                            1120
C                                                                      1130
      FMT(7)=F4                                                        1140
      DO 78 I = 1,NPT                                                  1150
      V(I) = SSUM(I) * R                                               1160
   78 CONTINUE                                                         1170
      WRITE (6,FMT)(FS(I),I=1,4),(V(J),J=1,NPT)                        1180
      WRITE (6,80)                                                     1190
   80 FORMAT ( 1H )                                                    1200
C                                                                      1210
C   MOLECULAR WEIGHT                                                   1220
C                                                                      1230
      FMT(7)= F3                                                       1240
      WRITE (6,FMT)(FM(I),I=1,4),(WM(J),J=1,NPT)                       1250
      DO 550 JAB=1,NPT
  550 TAB(LSP,7,JAB)=WM(JAB)
C                                                                      1260
C   (DLV/DLP)T                                                         1270
C                                                                      1280
      FMT(7)=F5                                                        1290
      IF(EQL) WRITE(6,FMT)(FV(I),I=1,4),(DLVPT(J),J=1,NPT)             1300
C                                                                      1310
C   (DLV/DLT)P                                                         1320
C                                                                      1330
      FMT(7)= F4                                                       1340
      IF(EQL) WRITE(6,FMT)(FD(I),I=1,4),(DLVTP(J),J=1,NPT)             1350
C                                                                      1360
C   HEAT CAPACITY                                                      1370
C                                                                      1380
```

```
      DO 85  I=1,NPT                                                    1390
      V(I) = CPR(I) * R                                                 1400
   85 CONTINUE                                                          1410
      WRITE(6,FMT)(FC(I),I=1,4),(V(J),J=1,NPT)                          1420
C                                                                       1430
C    GAMMA(S)                                                           1440
C                                                                       1450
      WRITE(6,FMT)(FG(I),I=1,4),(GAMMAS(J),J=1,NPT)                     1460
      DO 540 JAB=1,NPT
  540 TAB(LSP,3,JAB)=GAMMAS(JAB)
C                                                                       1470
C    SONIC VELOCITY                                                     1480
C                                                                       1490
      FMT(7)= F1                                                        1500
      DO 95 I = 1,NPT                                                   1510
      SONVEL(I) = SQRT(RR*GAMMAS(I)*TTT(I)/WM(I))                       1520
   95 CONTINUE                                                          1530
      WRITE(6,FMT)(FL(I),I=1,4),(SONVEL(J),J=1,NPT)                     1540
      RETURN                                                            1550
C                                                                       1560
      ENTRY OUT3                                                        1570
      IF(.NOT.EQL)  GO TO 331                                           1580
C                                                                       1590
C    MOLE FRACTIONS - EQUILIBRIUM                                       1600
C                                                                       1610
      WRITE (6,80)                                                      1620
      FMT(7)= F5                                                        1630
      WRITE(6,310)                                                      1640
  310 FORMAT(15HOMOLE FRACTIONS //)                                     1650
      DO 330 K=1,NS                                                     1660
      DO 315 I=1,NPT                                                    1670
      V(I) = EN(K,I) /TOTN(I)                                           1680
  315 CONTINUE                                                          1690
      DO 316 I=1,NPT                                                    1700
      IF (V(I).GE.(5.E-6)) GO TO 320                                    1710
  316 CONTINUE                                                          1720
      GO TO 330                                                         1730
  320 WRITE (6,FMT) SUB(K,1),SUB(K,2)          ,FB,(V(I),I=1,NPT)       1740
```

```
  330 CONTINUE                                                          1750
  331 WRITE(6,335)                                                      1760
  335 FORMAT(118HOADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MO 1770
     1LE FRACTIONS WERE LESS THAN .000005 FOR ALL ASSIGNED CONDITIONS//) 1780
      LINE= 0                                                           1790
      DO 350 K=1,NS                                                     1800
      DO 340 I=1,NPT                                                    1810
      IF ((EN(K,I)/TOTN(I)).GE.(5.E-6)) GO TO 343                       1820
  340 CONTINUE                                                          1830
      LINE= LINE+1                                                      1840
      Z(LINE,1)= SUB(K,1)                                               1850
      Z(LINE,2)= SUB(K,2)                                               1860
      Z(LINE,3)= SUB(K,3)                                               1870
  343 IF ((LINE.NE.10) .AND. K.NE.NS) GO TO 350                         1880
      IF (LINE.EQ.0) GO TO 1000                                         1890
      WRITE(6,345) (Z(LN,1),Z(LN,2),Z(LN,3),LN=1,LINE)                  1900
  345 FORMAT (10(1X,3A4))                                               1910
      LINE= 0                                                           1920
  350 CONTINUE                                                          1930
      IF(.NOT.MOLES) WRITE(6,360)                                       1940
  360 FORMAT(78HONOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXI 1950
     2DANT IN TOTAL OXIDANTS    )                                       1960
 1000 RETURN                                                            1970
      END                                                               1980
```

```
$ORIGIN        F
$IBFTC CECS5   DECK
C                                                                       10
      SUBROUTINE CPHS                                                   20
C     CALCULATES THERMODYNAMIC PROPERTIES FOR INDIVIDUAL SPECIES        30
C                                                                       40
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)   50
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)             60
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)  70
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2) 80
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)         90
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15) 100
     4 ,RHOP,RMW(15),TLN                                                110
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM  120
     1  ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ  130
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                       140
C                                                                       150
      EQUIVALENCE (J,JS1)                                               160
C                                                                       170
      K = 1                                                             180
      IF(TT.LE.TMID)K = 2                                               190
      KK = 0                                                            200
      CPSUM=0.                                                          210
   90 IF(COEF(K,1,J).NE.0.)GO TO 97                                     220
      IF (IUSE(J).LT.0) GO TO 100                                       230
      KK = K                                                            240
      K = 1                                                             250
      IF (KK.EQ.1) K = 2                                                260
   97 S(J) =  ((((COEF(K,5,J)/4.)*TT+ COEF(K,4,J)/3.)*TT+ COEF(K,3,J)/2. 270
     1)* TT+COEF(K,2,J))*TT+ COEF(K,1,J)*TLN + COEF(K,7,J)              280
      H0(J) = ((((COEF(K,5,J)/5.)*TT+ COEF(K,4,J)/4.)*TT+ COEF(K 3,J)/3. 290
     1  ) *TT+ COEF(K,2,J)/2.)*TT+ COEF(K,1,J) + COEF(K,6,J)/TT         300
      CPSUM= CPSUM+((((COEF(K,5,J)*TT+ COEF(K,4,J))*TT+ COEF(K,3,J))*TT 310
     1    + COEF(K,2,J))*TT+ COEF(K,1,J))*EN(J,NPT)                   320
      IF (KK.EQ.0) GO TO 100                                            330
      K = KK                                                            340
      KK = 0                                                            350
  100 IF(J.EQ.NS) GO TO 200                                             360
      J=J+1                                                             370
      GO TO 90                                                          380
  200 RETURN                                                            390
      END                                                               400
```

```
$IBFTC CECS6   DECK
      SUBROUTINE MATRIX                                                    10
C                                                                          20
C                                                                          30
      DOUBLE PRECISION G,X                                                 40
      LOGICAL HP,SP,TP,IDEBUG,CONVG,NEWR                                   50
C                                                                          60
      COMMON/POINTS/HSUM(13),SSUM(13),CPR(13),DLVTP(13),DLVPT(13)          70
     1 ,GAMMAS(13),P(26),T(26),V(13),PPP(13),WM(13),SONVEL(13),TTT(13)     80
     2,TOTN(13)                                                            90
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)      100
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)               110
      COMMON/MISC/ENN,SUMN,TT,SO,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)     120
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2)   130
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)            140
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15)   150
     4 ,RHOP,RMW(15),TLN                                                   160
      COMMON /DOUBLE/ G(20,21), X(20)                                      170
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM     180
     1  ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ    190
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                          200
C                                                                          210
      EQUIVALENCE (L,NLM)                                                  220
C                                                                          230
      IQ2 = IQ1 + 1                                                        240
      IQ3 = IQ2 + 1                                                        250
      KMAT = IQ3                                                           260
      IF(.NOT.CONVG.AND.TP) KMAT = IQ2                                     270
      IMAT = KMAT - 1                                                      280
C                                                                          290
C     CLEAR MATRIX STORAGES TO ZERO                                        300
C                                                                          310
      DO 211 I=1,IMAT                                                      320
      DO 211 K=1,KMAT                                                      330
      G(I,K)= 0.0D0                                                        340
  211 CONTINUE                                                             350
      SSS = 0.                                                             360
      HSUM(NPT) = 0.                                                       370
```

```
C                                                                       380
C     BEGIN SET UP OF ITERATION MATRIX                                  390
C                                                                       400
      KK = L                                                            410
      DO 65  J=1,NS                                                     420
      H=H0(J)*EN(J,NPT)                                                 430
      IF (.NOT.USE(J)) 65,11,70                                         440
   11 F = (H0(J)-S(J)+ENLN(J)+TM)*EN(J,NPT)                             450
      SS = H-F                                                          460
      TERM1 = H                                                         470
      IF (KMAT .EQ. IQ2) TERM1 = F                                      480
      DO 55 I = 1, L                                                    490
C                                                                       500
C     CALCULATE THE ELEMENTS  R(I,K)                                    510
C                                                                       520
      IF (A(I,J) .EQ. 0.) GO TO 55                                      530
      TERM= A(I,J)*EN(J,NPT)                                            540
      DO 15  K=I, L                                                     550
      G(I,K)= G(I,K) + A(K,J)*TERM                                      560
   15 CONTINUE                                                          570
C                                                                       580
      G(I,IQ1)=G(I,IQ1)+TERM                                            590
      G(I,IQ2)=G(I,IQ2)+A(I,J)*TERM1                                    600
      IF (CONVG .OR. TP) GO TO 55                                       610
      G(I,IQ3)= G(I,IQ3)+A(I,J)*F                                       620
      IF (SP) G(IQ2,I) = G(IQ2,I) + A(I,J)*SS                           630
   55 CONTINUE                                                          640
      IF (KMAT .EQ. IQ2) GO TO 64                                       650
      IF(CONVG.OR.HP) GO TO 59                                          660
      G(IQ2,IQ1) = G(IQ2,IQ1) + SS                                      670
      G(IQ2,IQ2)=G(IQ2,IQ2)+H0(J)*SS                                    680
      G(IQ2,IQ3) = G(IQ2,IQ3)+(S(J) - ENLN(J)-TM)*F                     690
      GO TO 62                                                          700
   59 G(IQ2,IQ2)=G(IQ2,IQ2)+H0(J)*H                                     710
      IF (CONVG) GO TO 64                                               720
      G(IQ2,IQ3)=G(IQ2,IQ3)+H0(J)*F                                     730
   62 G(IQ1,IQ3)=G(IQ1,IQ3)+F                                           740
   64 G(IQ1,IQ2)=G(IQ1,IQ2)+TERM1                                       750
```

```
      GO TO 65                                                          760
C                                                                       770
C    CONDENSED SPECIES                                                  780
C                                                                       790
   70 KK = KK + 1                                                       800
      DO 75  I = 1,L                                                    810
      G(I,KK) = A(I,J)                                                  820
      G(I,KMAT) = G(I,KMAT) - A(I,J)*EN(J,NPT)                          830
   75 CONTINUE                                                          840
      G(KK,IQ2) = HO(J)                                                 850
      G(KK,KMAT) = HO(J) - S(J)                                         860
      HSUM(NPT) = HSUM(NPT)+ H                                          870
      IF(.NOT.SP) GO TO 65                                              880
      SSS = SSS + S(J)*EN(J,NPT)                                        890
      G(IQ2,KK) = S(J)                                                  900
   65 CONTINUE                                                          910
      SSS = SSS + G(IQ2,IQ1)                                            920
      HSUM(NPT) = HSUM(NPT) + G(IQ1,IQ2)                                930
      G(IQ1,IQ1) = SUMN - ENN                                           940
C                                                                       950
C     REFLECT SYMMETRIC PORTIONS OF THE MATRIX                          960
C                                                                       970
      ISYM = IQ1                                                        980
      IF(HP.OR.CONVG)ISYM=IQ2                                           990
      DO 102 I=1,ISYM                                                  1000
      DO 102 J=I,ISYM                                                  1010
      G(J,I)=G(I,J)                                                    1020
  102 CONTINUE                                                         1030
C                                                                      1040
C     COMPLETE THE RIGHT HAND SIDE                                     1050
C                                                                      1060
      IF(CONVG)  GO TO 175                                             1070
      DO 145 I=1,L                                                     1080
      X(1)=BO(I)-G(I,IQ1)                                              1090
      G(I,KMAT) = G(I,KMAT)+X(1)                                       1100
  145 CONTINUE                                                         1110
      G(IQ1,KMAT) = G(IQ1,KMAT)+ENN-SUMN                               1120
C                                                                      1130
```

```
C       COMPLETE ENERGY ROW AND TEMPERATURE COLUMN                      1140
C                                                                       1150
        IF (KMAT .EQ. IQ2) GO TO 185                                    1160
        IF (SP)ENERGY = S0+ENN-SUMN - SSS                               1170
        IF(HP)ENERGY=HSUB0/TT - HSUM(NPT)                               1180
        G(IQ2,IQ3)=G(IQ2,IQ3)+ ENERGY                                   1190
  175   G(IQ2,IQ2)= G(IQ2,IQ2)+CPSUM                                    1200
  185   RETURN                                                          1210
        END                                                             1220
```

```
$IBFTC CECS7   DECK
      SUBROUTINE MGAUSD                                                      10
C                                                                            20
C     SOLVE ANY LINEAR SET OF UP TO 20 EQUATIONS                             30
C                                                                            40
      DOUBLE PRECISION G,X,COEFX(20),SUM,Z                                   50
C                                                                            60
      COMMON/DOUBLE/G(20,21),X(20)                                           70
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM       80
     1   ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ     90
     2  ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                           100
C                                                                           110
      EQUIVALENCE (IUSE,IMAT)                                               120
C                                                                           130
      DATA BIGNO/1.E+38/                                                    140
C                                                                           150
C     BEGIN ELIMINATION OF NNTH VARIABLE                                    160
C                                                                           170
      IUSE1=IUSE+1                                                          180
    6 DO 45 NN=1,IUSE                                                       190
      IF (NN-IUSE) 8,83,8                                                   200
   83 IF(G(NN,NN))31,23,31                                                  210
C                                                                           220
C     SEARCH FOR MAXIMUM COEFFICIENT IN EACH ROW                            230
C                                                                           240
    8 DO 18 I=NN,IUSE                                                       250
      COEFX(I) = BIGNO                                                      260
      IF(G(I,NN).EQ.0.)  GO TO 18                                           270
      COEFX(I) = 0.                                                         280
      DO 10 J=NN,IUSE1                                                      290
      SUM = G(I,J)                                                          300
      IF(SUM.LT.0.)  SUM=-SUM                                               310
      IF(J.NE.NN)  GO TO 9                                                  320
      Z = SUM                                                               330
      GO TO 10                                                              340
    9 IF(SUM.GT.COEFX(I))  COEFX(I)=SUM                                     350
   10 CONTINUE                                                              360
      COEFX(I) = COEFX(I)/Z                                                 370
```

```
   18 CONTINUE                                                          380
      TEMP = BIGNO                                                      390
      I=0                                                               400
   20 DO 22 J=NN,IUSE                                                   410
      IF (COEFX(J)-TEMP) 87,22,22                                       420
   87 TEMP=COEFX(J)                                                     430
      I=J                                                               440
   22 CONTINUE                                                          450
      IF(I) 28,23,28                                                    460
C                                                                       470
C     INDEX I LOCATES EQUATION TO BE USED FOR ELIMINATING THE NTH       480
C     VARIABLE FROM THE REMAINING EQUATIONS                             490
C                                                                       500
C      INTERCHANGE EQUATIONS I AND NN                                   510
C                                                                       520
   28 IF(NN-1) 29,31,29                                                 530
   29 DO 30 J=NN,IUSE1                                                  540
      Z=G(I,J)                                                          550
      G(I,J)=G(NN,J)                                                    560
      G(NN,J)=Z                                                         570
   30 CONTINUE                                                          580
C                                                                       590
C     DIVIDE NTH ROW BY NTH DIAGONAL ELEMENT AND ELIMINATE THE NTH      600
C     VARIABLE FROM THE REMAINING EQUATIONS                             610
C                                                                       620
   31 K = NN + 1                                                        630
      DO 36 J = K, IUSE1                                                640
      IF(G(NN,NN).EQ.0.)  GO TO 23                                      650
           G(NN,J) = G(NN,J) / G(NN,NN)                                 660
   36 CONTINUE                                                          670
      IF(K-IUSE1) 88,45,88                                              680
   88 DO 44 I = K,IUSE                                                  690
   40 DO 44 J = K, IUSE1                                                700
           G(I,J) = G(I,J) - G(I,NN)*G(NN,J)                            710
   44 CONTINUE                                                          720
   45 CONTINUE                                                          730
C                                                                       740
C     BACKSOLVE FOR THE VARIABLES                                       750
```

```
C                                                                       760
      K = IUSE                                                          770
   47 J = K + 1                                                         780
      X(K) = 0.0D0                                                      790
      SUM = 0.0                                                         800
      IF(IUSE - J) 51,48,48                                             810
   48 DO 50 I = J,IUSE                                                  820
            SUM = SUM + G(K,I)* X(I)                                    830
   50 CONTINUE                                                          840
   51 X(K) = G(K,IUSE1) - SUM                                           850
      K = K - 1                                                         860
      IF (K) 47,151,47                                                  870
   23 IUSE = IUSE-1                                                     880
  151 RETURN                                                            890
      END                                                               900
```

```
$ORIGIN         E
$IBFTC CECS2    DECK
C                                                                       10
      SUBROUTINE REACT                                                  20
C                                                                       30
      DOUBLE PRECISION G,X                                              40
      LOGICAL HP,SP,TP,IDEBUG,CONVG,NEWR,IONS,MOLES,EQL,FROZ            50
C                                                                       60
      DIMENSION ANAME(15,5),V(15)                                       70
C                                                                       80
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)  90
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2) 100
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)         110
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15) 120
     4 ,RHOP,RMW(15),TLN                                                130
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM  140
     1  ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ  150
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JS1                       160
C                                                                       170
      EQUIVALENCE (NAME,ANAME),(NLM,L)                                  180
C                                                                       190
      DATA MOL/1HM/,OX/1HO/,LANK/1H /,IZERO/2H00/                       200
      DATA MOLE/1H /
C                                                                       210
      DO 10 K=1,2                                                       220
      WP(K)=0.                                                          230
      HPP(K)=0.                                                         240
      RHO(K)=0.                                                         250
      VPLS(K)=0.                                                        260
      VMIN(K)=0.                                                        270
      AC(K)=0.                                                          280
      AM(K)=0.                                                          290
      DO 8 J=1,15                                                       300
      LLMT(J)=0                                                         310
      B0P(J,K)=0.                                                       320
    8 CONTINUE                                                          330
   10 CONTINUE                                                          340
      N=1                                                               350
```

```
      L=1                                                                   360
   20 CONTINUE
   21 FORMAT(5(A2,F7.5),F7.5,A1,F9.5,A1,F8.5,A1,F8.5)                       390
      IF(NAME(N,1).EQ.LANK) GO TO 200                                       400
      IF(L.EQ.0)GO TO 20                                                    410
      WRITE (6,31)(NAME(N,I),ANUM(N,I),I=1,5),PECWT(N),MOLE,ENTH(N),FAZ     420
     1  (N),RTEMP(N),FOX(N),DENS(N)                                         430
   31 FORMAT(1X,5(A2,1X,F7.4,2X),F8.4,2X,A1,F11.2,2X,A1,2X,F8.3,2X,         440
     1A3,3X,F8.5)
   35 IF(MOLE.EQ.MOL) MOLES=.TRUE.                                          460
      K=2                                                                   470
      IF(FOX(N).EQ.OX)K=1                                                   480
      DO 38 J=1,15                                                          490
      DATA(J) = 0.                                                          500
   38 CONTINUE                                                              510
      RM=0.                                                                 520
      DO 100 JJ=1,5                                                         530
      IF(ANUM(N,JJ).EQ.0.)GO TO 101                                         540
      DO 41 J=1,15                                                          550
      NJ = J                                                                560
      IF(LLMT(J).EQ.0) GO TO 45                                             570
      IF(NAME(N,JJ).EQ.LLMT(J))GO TO 46                                     580
   41 CONTINUE                                                              590
   45 L = NJ                                                                600
      LLMT(J)=NAME(N,JJ)                                                    610
   46 DO 48 KK=1,101                                                        620
      IF(ATOM(1,KK).EQ.ANAME(N,JJ))GO TO 50                                 630
   48 CONTINUE                                                              640
      L=0                                                                   650
      GO TO 20                                                              660
   50 RM=RM+ANUM(N,JJ)*ATOM(2,KK)                                           670
      V(J)=ATOM(3,KK)                                                       680
      DATA(J)=ANUM(N,JJ)                                                    690
  100 CONTINUE                                                              700
  101 PCWT=PECWT(N)                                                         710
      IF(MOLES) PCWT=PCWT*RM                                                720
      WP(K)=WP(K) + PCWT                                                    730
      IF(NAME(N,5).NE.IZERO)HPP(K)=HPP(K)+ENTH(N)*PCWT/RM                   740
```

```
      AM(K)=AM(<)+PCWT/RM                                                    750
      DO 110   J=1,L                                                         760
      BOP(J,K)=DATA(J)*PCWT/RM +BOP(J,K)                                     770
  110 CONTINUE                                                               780
      IF(DENS(N).NE.0.)GO TO 115                                             790
      GO TO 117                                                              800
  115 RHO(K)=RHO(K)+PCWT/DENS(N)                                             810
  117 RMW(N) = RM                                                            820
      N = N+1                                                                830
      IF(N.NE.16) GO TO 20                                                   840
  200 NREAC =N-1                                                             850
      IF(L.EQ.0) GO TO 1000                                                  860
      DO 220 K=1,2                                                           870
      IF(WP(K).EQ.0.)GO TO 220                                               880
      HPP(K)=HPP(K)/WP(K)                                                    890
      AM(K) = WP(K)/AM(K)                                                    900
      IF(RHO(K).NE.0.)RHO(K)=WP(K)/RHO(K)                                    910
      DO 215 J=1,L                                                           920
      BOP(J,K)=BOP(J,K)/WP(K)                                                930
      IF(V(J).LT.0.)VMIN(K)= VMIN(K)+BOP(J,K)*V(J)                           940
      IF(V(J).GT.0.)VPLS(K)=VPLS(K)+BOP(J,K)*V(J)                            950
  215 CONTINUE                                                               960
      IF(MOLES) GO TO 220                                                    970
      DO 218 N=1,NREAC                                                       980
      IF(FOX(N).EQ.OX.AND.K.EQ.2)   GO TO 218                                990
      IF(FOX(N).NE.OX.AND.K.EQ.1)   GO TO 218                               1000
      PECWT(N) = PECWT(N)/WP(K)                                             1010
  218 CONTINUE                                                              1020
  220 CONTINUE                                                              1030
      NEWR=.TRUE.                                                           1040
      DO 230 N = 1,NREAC                                                    1050
      IF (DENS(N).NE.0.) GO TO 230                                          1060
      RHO (1) = 0.                                                          1070
      GO TO 1000                                                            1080
  230 CONTINUE                                                              1090
 1000 RETURN                                                                1100
      END                                                                   1110
```

```
$IBFTC CECS3
      SUBROUTINE SEARCH                                                    10
C                                                                          20
C  SEARCH TAPE FOR THERMO DATA FOR SPECIES TO BE CONSIDERED                30
      INTEGER SUB,OMIT,END                                                 40
C                                                                          50
      LOGICAL NEWR                                                         60
C                                                                          70
      DIMENSION DATE(2,3),MT(4),B(4),OMIT(3,3)                             80
C                                                                          90
      COMMON/SPECES/COEF(2,7,150),S(150),EN(150,13),ENLN(150),H0(150)     100
     1 ,DELN(150),A(15,150),SUB(150,3),IUSE(150),TEMP(50,2)               110
      COMMON/MISC/ENN,SUMN,TT,S0,ATOM(3,101),LLMT(15),B0(15),B0P(15,2)     120
     1 ,TM,TLOW,TMID,THIGH,PP,CPSUM,OF,EQRAT,FPCT,R,RR,HSUB0,AC(2),AM(2)  130
     2 ,HPP(2),RHO(2),VMIN(2),VPLS(2),WP(2),DATA(22),NAME(15,5)           140
     3 ,ANUM(15,5),PECWT(15),ENTH(15),FAZ(15),RTEMP(15),FOX(15),DENS(15)  150
     4 ,RHOP,RMW(15),TLN                                                  160
      COMMON/INDX/ IDEBUG,CONVG,TP,HP,SP,HPSP,TPSP,MOLES,NP,NT,NPT,NLM     170
     1  ,NS,KMAT,IMAT,IQ1,IQ2,NOMIT,IP,NEWR,NSUB,NSUP,ITN,CPCVFR,CPCVEQ    180
     2 ,IONS,NC,NSERT,JSOL,JLIQ,KASE,NREAC,IC,JSI                         190
C                                                                          200
      EQUIVALENCE (DATE,EN),(OMIT,ENLN),(ENDD,END),(L,NLM)                 210
      COMMON/TAPE/IPROT
C                                                                          220
      DATA  GAS/1HG/,END/3HEND/                                            230
C                                                                          240
      NC= 0                                                                250
      IX= 0                                                                260
      COEF(1,1,1) = ENDD                                                   270
      I = I                                                                280
      DO 3 I=1,150                                                         290
      IF(A(1,I).EQ.ENDD)  GO TO 4                                          300
      DO 3  J=1,L                                                          310
      A(J,I) = 0.                                                          320
    3 CONTINUE                                                             330
    4 MAXNS = I                                                            340
      REWIND 8
      REWIND 10
```

```
      GO TO 50
      IF(IPROT.EQ.1)GO TO 50
      READ(8    )TLOW,TMID,THIGH
    5 FORMAT (3F10.3)                                                    370
      NS = 1                                                             380
    7 READ(8    )  (SUB(NS,I),I=1,2),DATE(1,NS),DATE(2,NS),(MT(J),B(J),
     1  J=1,4),PHAZ,T1,T2
   10 FORMAT(2A6,6X,2A3,4(A2,F3.0),A1,2F10.3)                            410
      IF(SUB(NS,1).EQ.END) GO TO 171                                     420
      READ(8    )    ((COEF(I,J,NS),J=1,7),I=1,2)
      GO TO 75
   50 CONTINUE
      READ(10,5 )TLOW,TMID,THIGH
      NS = 1
    8 CONTINUE
      READ(10,10)  (SUB(NS,I),I=1,2),DATE(1,NS),DATE(2,NS),(MT(J),B(J),
     1  J=1,4),PHAZ,T1,T2
      IF(SUB(NS,1).EQ.END) GO TO 171
      READ(10,20)    ((COEF(I,J,NS),J=1,7),I=1,2)
   75 CONTINUE
   20 FORMAT (5E15.8)                                                    440
      IF(NOMIT.EQ.0) GO TO 810                                           450
      DO 805 I=1,NOMIT                                                   460
      DO 804 J=1,3                                                       470
      IF(OMIT(J,I).NE.SUB(NS,J)) GO TO 805                               480
  804 CONTINUE                                                           490
      GO TO 8
      IF(IPROT.EQ.1)GO TO 8
      GO TO 7                                                            500
  805 CONTINUE                                                           510
  810 DO 820 K=1,4                                                       520
      IF(B(K).EQ.0.) GO TO 825                                           530
      DO 168 I=1,L                                                       540
      IF(LLMT(I).EQ.MT(K)) GO TO 820                                     550
  168 CONTINUE                                                           560
      DO 819 J=1,L                                                       570
  819 A(J,NS) = 0.                                                       580
      GO TO 8
```

```
      IF(IPROT.EQ.1)GO TO 8
      GO TO 7                                                          590
  820 A(I,NS)= B(K)                                                    600
  825 IF(NS.EQ.MAXNS)  GO TO 870                                       610
      IUSE(NS)= 0                                                      620
      IF(PHAZ.EQ.GAS) GO TO 170                                        630
      NC= NC+1                                                         640
      TEMP(NC,1)= T1                                                   650
      TEMP(NC,2)= T2                                                   660
      IX= IX+1                                                         670
      IF(IUSE(NS-1).EQ.0 .OR. NC.EQ.1) GO TO 145                       680
      DO 830 I=1,L                                                     690
      IF(A(I,NS).NE.A(I,NS-1)) GO TO 145                               700
  830 CONTINUE                                                         710
      IX= IX-1                                                         720
  145 IUSE(NS)= -IX                                                    730
  170 NS= NS+1                                                         740
      GO TO 8
      IF(IPROT.EQ.1)GO TO 8
      GO TO 7                                                          750
  870 WRITE(6,871) (SUB(NS,J),J=1,2)
  871 FORMAT (45HODIMENSIONS IN/SPECES/TOO SMALL TO CONSIDER ,2A6)     770
      GO TO 8
      IF(IPROT.EQ.1)GO TO 8
      GO TO 7                                                          780
  171 NS= NS-1                                                         790
      NEWR= .FALSE.                                                    800
      WRITE(6,172)                                                     810
  172 FORMAT(42HOSPECIES BEING CONSIDERED IN THIS SYSTEM               820
      DO 174 I=1,NS,5                                                  830
      I5= I+4                                                          840
      IF(NS.LT.I5) I5=NS                                               850
  174 WRITE (6,176)(DATE(1,J),DATE(2,J),SUB(J,1),SUB(J,2)          ,J=I,  8
     1  I5)                                                           870
  176 FORMAT(5(5X,2A3,2X,2A6))                                         88
      RETURN                                                           890
      END                                                              900
```

```
$DATA
          TRIAL RUN SIMULANT SELECTION
     3     3     0     0     0     0     1
  +.0314       +.1        +20.0        +0.0
  +.314        +20.       +0.0         +100.
H +13.0220 2.17040N 4.34070                        F L      .5     -5900.      298.15
N 2.173600 4.3472                                  O L      .5     +27560.     298.15
   10.        11.        12.          1.0
```

(2) (1) TRIAL RUN SIMULATION SELECTION

NMIX= 2 NPTS= 3 IP= 0 IT= 0 IG= 0 IFLG1= 0 ITYPE= 1

(3) NOZZLE GEOMETRY FOLLOWS

THROAT AREA	THROAT RADIUS	AREA RATIO	LIP ANGLE
0.314E-01	0.100E 00	0.200E 02	0.000E-38

(4)

INITIAL CHAMBER TEMP= 0.100E 04 PRESSURE= 0.200E 03

(5) PROTOTYPE INFORMATION

RADP= 0.314E 00AETP= 0.200E 02ANGP= 0.000E-38PREP= 0.100E 03

(6) REGION OF PLUME TO BE DUPLICATED

XP1= 0.100E 02 XP2= 0.110E 02 XP3= 0.120E 02

(7)

ERROR MULTIPLICATION FACTOR = 0.100E 01

(8) THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

PC = 100 0 PSIA
CASE NO *****

	CHEMICAL FORMULA				WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H ********	O 2.17040	N 4 34070		*******	-5900.000	L	298.15	-0.0000
OXIDANT	N 2 17360	O + 34720			*******	27560.000	L	298.15	-0.0000

O/F= 1.0000 PERCENT FUEL= 50 0000 EQUIVALENCE RATIO= 0 9445 DENSITY= -0.0000

P/P	CHAMBER 1 000	THROAT 1.787	EXIT 25 000	EXIT 300.000	EXIT 1000 00	EXIT 2000 00	EXIT 3000.00	EXIT 4000.00	EXIT 5000.00	EXIT 7000.00	EXIT 10000 0	EXIT 30000.0	EXIT 60000 0
P, ATM	5.805	3 807	0.2722	0.0227	0 0068	0.0034	0 0023	0.0017	0.0014	0.0010	0.0007	0.0002	0.0001
T, DEG K	3140	2324	1701	996	748	629	568	527	498	456	415	310	257
H, CAL/G	110 7	-61 6	-945 6	-973.2	-1077.2	-1124 6	-1148.7	-1154.4	-1175.8	-1191.7	-1207 2	-1246.6	-1266 1
S, CAL/(G)(K)	3 1868	3 1868	3 1868	3 1868	3.1863	3.1858	3.1868	3.1868	3 1868	3.1868	3.1868	3.1868	3.1869
M, MOL WT	19 961	19 961	19 961	19 961	19 961	19.961	19 961	19.961	19.961	19.961	19.961	19.961	19.961
CP, CAL/(G)(K)	0 5484	0 5408	0 4921	0.4324	0 4056	0 3947	0.3890	0.3855	0 3831	0.3799	0.3771	0.3718	0.3703
GAMMA (S)	1 2218	1 2256	1 2596	1.2991	1.3243	1.3373	1.3440	1.3482	1 3511	1.3551	1.3586	1.3657	1.3678
SON VEL,M/SEC	1254.1	1200 7	942 3	734 0	642 3	592 1	565.8	544 2	529.2	507.3	484 6	419.8	382 8
MACH NUMBER	0 000	1.000	2.670	4.103	4 909	5.430	5.758	6.003	6.199	6.508	6.852	8.027	8.866
CSTAR, FT/SEC		5745	5745	5745	5745	5745	5745	5745	5745	5745	5745	5745	5745
CF		0 686	1.437	1 720	1 800	1.836	1 854	1.865	1.874	1 885	1.896	1.925	1.939
AE/AT		1.000	4.020	23 59	56 43	93 14	124.8	153.6	180.4	229.9	297.3	656.1	1081 7
IVAC,LB-SEC/LB		222 3	285 2	321.1	331 6	338 2	338.5	339.9	341.0	342.5	343.9	347.6	349.3
I, LB-SEC/LB		122.4	256 5	307 1	321 5	327 8	331.0	333.1	334 6	336 6	338.6	343.6	346.1
RHOISP		-0 0	-0 0	-0 0	-0 0	-0 0	-0.0	-0.0	-0.0	-0 0	-0 0	-0.0	-0 0

MOLE FRACTIONS

	1 H2		H2		0.736E-01		0 736E-01						
	2 H2O		H2O		0.482E 00		0.482E 00						
H	Q000	0.02+65	H02	Q000	0 00003	H2	Q000	0.07356	H2O	Q000	0.48203		
	3		N2		0 301E 00		0 301E 00						
N	Q000	0 00001	N2	Q000	0 30077	NO	Q000	0.01412	NO2	Q000	0.00001		
	4 OH		OH		0 604E-01		0 604E-01						
O	Q000	0.01225	OH	Q000	0 05036	O	Q000	0.03222					

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN 00005 FOR ALL ASSIGNED CONDITIONS

H2O2 Q000 H2O1 Q000 NH Q000 NH2 Q000 NH3 Q000 N2H4 Q000 N2O Q000 N2O4 Q000

NOTE WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

(9)

H FT2/S2	A/A*	GAMMA	M NØ.	P PSF	T DEG R	MØL WT
0.499E 07	-0.000E- 9	0.122E 01	0.000E-35	0.144E 03	0.565E 04	0.200E 02
-0.273E 07	0.100E 01	0.122E 01	0.100E 01	0.806E 04	0.508E 04	0.200E 02
-0.21.E 04	0.402E 0	0.125E 01	0.267E 01	0.576E 03	0.306E 04	0.200E 02

(10) PRØTØTYPE EXIT PLANE REYNØLDS NØ. IS 0.230E 05

(11) ØRIGIN ØF SØURCE FLØW AT X=-0.121E 00

(12) WITH THETA= 0.148E 01

(13) S2	(14) MACH NØ	(15) RE NØ	(16) GAMMA	(17) KNUDSEN NØ	(18) TØ	(19) T	(20) PO	(21) P
0.4809E 01	0.4793E 01	0.3874E 05	0.1322E 01	0.1416E-04	0.7124E 04	0.1098E 04	0.6585E 04	0.6018E 02
0.7617E 01	0.3774E 01	0.6129E 05	0.1344E 01	0.4561E-03	0.7124E 04	0.1018E 04	0.6585E 04	0.2535E 02
0.1043E 02	0.6565E 01	0.3232E 05	0.1356E 01	0.9328E-03	0.7124E 04	0.8038E 03	0.6585E 04	0.7098E 01

(22) PRØTØTYPE CØNDENSATIØN ØCCURS AT 0.502E 03

(23) THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AT ALL ASSIGNED TEMPERATURES

P, = 200.0 PSIA
CASE NO. 1

	CHEMICAL FORMULA		WT FRACTION (SEE NOTE)	ENTHALPY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C 1.00000	F 4.00000	*******	-217200.000	G	298.15	-0.0000
FUEL	N 2.00000		*******	0.000	G	298.15	-0.0000
FUEL	C 1.00000	O 2.00000	*******	-94051.800	G	298.15	-0.0000

O/F= 0.0000 PERCENT FUEL=******** EQUIVALENCE RATIO= 1.0000 DENSITY= 0.0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
P/P	1.000	1.776	25.000	300.000	1000.00	2000.00	3000.00	4000.00	5000.00	7000.00
P, ATM	13.61	7.664	0.5444	0.0454	0.0136	0.0068	0.0045	0.0034	0.0027	0.0019
T, DEG K	1000	907	563	339	258	219	198	184	174	159
H, CAL/G	-1242.2	-1267.7	-1356.7	-1408.0	-1424.6	-1432.3	-1436.2	-1438.8	-1440.6	-1443.2
S, CAL/(G)(K)	1.4026	1.4026	1.4026	1.4026	1.4026	1.4026	1.4026	1.4026	1.4026	1.4026
M, MOL WT	42.793	42.793	42.793	42.793	42.793	42.793	42.793	42.793	42.793	42.793
CP, CAL/(G)(K)	0.2767	0.2715	0.2434	0.2123	0.1977	0.1898	0.1855	0.1825	0.1803	0.1770
GAMMA (S)	1.2017	1.2063	1.2358	1.2799	1.3070	1.3238	1.3340	1.3413	1.3470	1.3556
SOS VEL,M/SEC	483.2	461.1	367.8	290.5	256.1	237.2	226.5	219.0	213.3	204.8
MACH NUMBER	0.000	1.000	2.660	4.054	4.823	5.316	5.625	5.855	6.041	6.332
CSTAR, FT/SEC		2227	2227	2227	2227	2227	2227	2227	2227	2227
CF		0.679	442	1.735	1.820	1.858	1.877	1.889	1.898	1.910
AE/AT		1.000	43.20	24.75	59.86	99.32	133.4	164.3	193.1	246.1
IVAC,LB-SEC/LB		86.0	111.2	125.8	130.1	132.0	133.0	133.6	134.1	134.7
I, LB-SEC/LB		47.0	99.8	120.1	126.0	128.6	129.9	130.8	131.4	132.2
RHOISP		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

MOLE FRACTIONS

1	CF4	CF4	0.145E 00	0.145E 00
2	COF2	COF2	0.995E-01	0.995E-01
3	C02	C02	0.145E 00	0.145E 00
4	N2	N2	0.611E 00	0.611E 00

CF4 Q000 0.14475 COF2 Q000 0.09951 C02 Q000 0.14471 N2 Q000 0.61103

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .000005 FOR ALL ASSIGNED CONDITIONS

C(S)	Q000 CF	Q000 CF2	Q000 CF3	Q000 CN	Q000 CN2	Q000 CO	Q000 COF	Q000 C2	Q000 C2F2	Q000
C-1	Q000 C2N2	Q000 C2O	Q000 CO2	Q000 F	Q000 FCN	Q000 FO	Q000 FO2	Q000 F2	Q000 N	Q000
NO	Q000 NF2	Q000 NF3	Q000 NO	Q000 NOF	Q000 NO2	Q000 NO2F	Q000 N2O	Q000 N2O	Q000 N2O4	Q000
O	Q000 O2	Q000								

NOTE WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

(24)

(30) TABLE ØF THERMØDYNAMIC PRØPERTIES FØR MIXTURE

H FT2/S2	A/A*	GAMMA	M NØ.	P PSF	T DEG R	MØL WT
-0.560E 08	-0.000E-19	0.120E 01	0.000E-38	0.288E 05	0.180E 04	0.428E 02
-0.571E 08	0.100E 01	0.121E 01	0.100E 01	0.162E 05	0.163E 04	0.428E 02
-0.611E 08	0.412E 01	0.124E 01	0.266E 01	0.115E 04	0.101E 04	0.428E 02
-0.634E 08	0.247E 02	0.128E 01	0.407E 01	0.960E 02	0.610E 03	0.428E 02

(25)

TABLE ØF THERMØDYNAMIC PRØPERTIES FØR CØMPØNENT 1

H FT2/S2	A/A*	GAMMA	M NØ.	P PSF	T DEG R	MØL WT
-0.101E 09	-0.000E-19	0.111E 01	0.000E-38	0.288E 05	0.180E 04	0.733E 02
-0.102E 09	0.100E 01	0.111E 01	0.100E 01	0.168E 05	0.170E 04	0.733E 02
-0.105E 09	0.483E 01	0.112E 01	0.261E 01	0.115E 04	0.129E 04	0.733E 02
-0.107E 09	0.350E 02	0.113E 01	0.374E 01	0.960E 02	0.977E 03	0.733E 02

(26)

TABLE ØF THERMØDYNAMIC PRØPERTIES FØR CØMPØNENT 2

H FT2/S2	A/A*	GAMMA	M NØ.	P PSF	T DEG R	MØL WT
-0.110E 08	-0.000E-19	0.130E 01	0.000E-38	0.288E 05	0.180E 04	0.302E 02
-0.127E 08	0.100E 01	0.132E 01	0.100E 01	0.156E 05	0.156E 04	0.302E 02
-0.175E 08	0.354E 01	0.136E 01	0.271E 01	0.115E 04	0.805E 03	0.302E 02
-0.200E 08	0.184E 02	0.139E 01	0.440E 01	0.960E 02	0.407E 03	0.302E 02
-0.207E 08	0.423E 02	0.139E 01	0.539E 01	0.288E 02	0.292E 03	0.302E 02

SIMULANT RN AT EXIT = 0.104E 06

GROUP 11

— ORIGIN OF SOURCE FLOW AT X= 0.136E-01 WITH THETA= 0.160E 01

GROUP 12

S2	MACH NO	RE NO	GAMMA	KNUDSEN NO	TO	T	PO	P	
0.1394E 01	0.4681E 01	0.5938E 08	0.1304E 01	0.2587E-05	0.2113E 04	0.4878E 03	0.1923E 05	0.1278E 03	
0.2239E 01	0.5592E 01	0.8812E 07	0.1333E 01	0.8181E-05	0.2236E 04	0.3602E 03	0.1494E 05	0.3548E 02	
0.3183E 01	0.6438E 01	0.4103E 07	0.1356E 01	0.2129E-04	0.2331E 04	0.2785E 03	0.1221E 05	0.9935E 01	
0.4078E 01	0.7105E 01	0.2753E 07	0.1356E 01	0.3494E-04	0.2331E 04	0.2336E 03	0.1221E 05	0.3676E 01	

SIMULANT CONDENSATION PT. IS 0.225E 02